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APPLICATIONS OF THE PETITE AMATEUR NAVY SATELLITE (PANSAT)

by

Robert Andrew Payne Jr.

September 1992

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APPLICATIONS OF THE PETITE
AMATEUR NAVY SATELLITE
(PANSAT)

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Submitted in partial fulfillment of the
requirements for the degree of

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ABSTRACT

This thesis provides an analysis of potential Petite Amateur Navy Satellite (PANSAT) system users. At a point in time where large satellite designers are just now beginning to focus their efforts towards capturing a portion of the rapidly expanding light satellite (lightsat) market, the Naval Postgraduate School is designing a lightsat unlike any which has been built before or will be built in the foreseeable future. A single PANSAT (or an entire constellation) can be lofted into orbit at a relatively low cost as a secondary payload on a variety of launch vehicles. Its design makes it an ideal system for providing store and forward communications to a large number of users at a fraction of the cost of most (if not all other) satellite systems. The long-term success of this program relies not only on the technical aspects of design and production but also on the Naval Postgraduate School's ability to create a satellite system that provides maximum utility to potential user communities yet to be explicitly defined.

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I. INTRODUCTION

A. GENERAL

The Naval Postgraduate School (NPS) is currently developing the Petite Amateur Navy Satellite (PANSAT) in collaboration with the amateur radio community. PANSAT is an experiment in low-earth orbit (LEO), small satellite communications. It is a proof of concept design for digital, spread spectrum, store-and-forward, packet radio, personal computer based satellite communications.

NPS is designing and fabricating PANSAT on campus in Monterey, CA and will collaborate with the amateur radio community during the post-launch testing phase. Figure 1 shows a cut-out view of PANSAT.

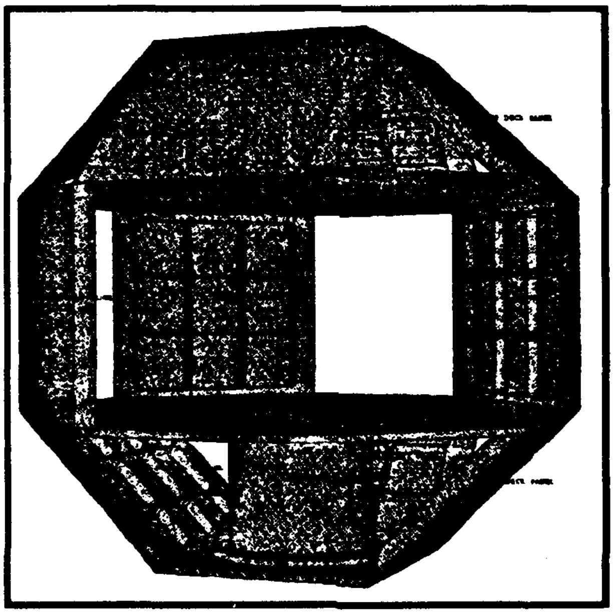

Figure 1: PANSAT with some panels removed to view interior

As proof of concept, PANSAT is to provide communications support to the amateur radio community. Amateur radio operators are currently using radio frequencies for non spread spectrum, packet radio and store-and-forward

communications. Spread spectrum modulation provides the advantages of Low Probability of Intercept (LPI), Low Probability of Detection (LPD), resistance to jamming, and low probability of interference (to and from other users in the band). An example of military application to this type of communication would be the transmission of logistical requests from the sands of Saudi Arabia to the United States (as done during Operation Desert Shield/Desert Storm).

PANSAT's focus could be enhanced if a need and capability which extended beyond the amateur radio community could be established. The major issue for this thesis involves identifying potential PANSAT system users and comparing their communication requirements with the current PANSAT design approach to determine what changes to PANSAT would be required to support these users. Other factors such as increased satellite cost and complexity must be quantified before implementing any recommended changes.

B. OBJECTIVES

The primary objective of this thesis was to define potential operational uses for the NPS's PANSAT. This objective was accomplished by reviewing the current PANSAT design and comparing and contrasting projected capabilities with potential military and non-military PANSAT system users. The secondary objective was to recommend changes to the current design concept and/or possible follow-on NPS satellites. This objective was accomplished by examining the user requested capabilities which could not be fulfilled with the current PANSAT design.

C. PROBLEM STATEMENT

Given that the design, testing, deployment and operation of PANSAT's current configuration is successful, what type of utility does PANSAT provide for what types of users? If specific modifications to the current design are made to

accommodate other potential users, who are those users, what changes could be made, and what are the possible trade-offs for making such changes?

D. CURRENT PANSAT DESIGN

1. Hardware Configuration

PANSAT is a light satellite (lightsat) designed to weigh 150 lbs. It is 19" in diameter and 18.5" high in the longitudinal axis. This size will enable PANSAT to be launched by one of the Space Shuttle's free flyer Get Away Special (GAS) launch canisters. Because of its small size, PANSAT could also be launched by Pegasus, Scout, and as a secondary payload by Delta II, Titan II and Taurus launch vehicles. See Appendix A for a summary of possible U.S. military, PANSAT launch vehicles.

PANSAT is a 26-sided polyhedron with 18 square panels (17 solar panels and one launch vehicle interface) and eight triangular panels (four of which are antenna mounts and four of which may be used for experiments). It will not have an attitude control system and will slowly tumble. As such, the satellite's antennas must be omni-directional. Because antenna orientations are not known, the antennas are circular polarized.

2. Communications Parameters

PANSAT will serve as a store-and-forward data relay experiment for NPS and other selected users in the amateur radio community. It will utilize spread spectrum modulation as a proof of concept for small satellite communications. It will be able to operate with simple Bipolar Phase Shift Keying (BPSK) modulation as a backup in case of a spread spectrum modulation system failure.

PANSAT will operate in a full-duplex mode, allowing simultaneous, two-way signalling. This type of operation maximizes user-satellite interaction speed

and has the advantage of being able to provide communication in both directions at once. [Ref. 1:p. 8-17]

Both PANSAT and system users will the utilize amateur packet radio's AX.25 link-layer protocol to send and receive messages of variable lengths (see Appendix B for an overview of the AX.25 link layer protocol and associated user terminal equipment). PANSAT will have approximately three megabytes of user-accessible memory and will transmit and receive data at a data rate of 1200 or 2400 baud. PANSAT will have a total signal transmission power of six watts. It will operate with a 1 MHz bandwidth at a center frequency of 437.25 MHz. [Ref. 2]

3. Ground and User Stations

The main control station will be located on the NPS campus. A backup station will probably be built and would be positioned elsewhere on the Monterey Peninsula. Users should be able to access the satellite from any position on Earth with a personal computer, a Terminal Node Controller (TNC), appropriate software and a satellite dish transmit / receive system (see Appendix B for a general description of TNC functions). PANSAT's spread spectrum capability will also require users to obtain special spread spectrum hardware and/or software. Because of PANSAT's low earth orbit, transmission power and antenna gain requirements will be far less than what is normally required to transmit and receive from geostationary orbiting (GSO) satellites.

4. Security Considerations

PANSAT will not use any Department of Defense (DoD) encryption or decryption equipment. It will use password protection to prevent unauthorized users from logging on to the system.

E. RESEARCH QUESTIONS

1. General

The focal point of this thesis was the identification of PANSAT users and PANSAT system features required to support these users. However, to address PANSAT user needs and supporting features, a number of questions need to be answered. Some of the possible questions follow. What are the other existing or proposed satellite systems similar to PANSAT? What are the lessons learned from these systems? Can NPS gain approval to operate PANSAT on UHF military frequencies? Who are the key potential users of PANSAT? What requirements must the user terminal satisfy? Are there "off the shelf," commercially available user terminal/components to support key potential users? How can key potential users be integrated into PANSAT's final operational testing?

2. Possible Design Modifications

In order to accommodate key potential users, it may be necessary to modify PANSAT's current design. However, before any major design modifications are made, several questions need to be answered in order to ensure the optimization of the design to accommodate as many potential users as possible. Some of the possible questions follow. Are data rates of 1200 to 2400 baud sufficient to support all potential user requirements? What is the minimum required RAM for the store-and-forward mailbox? Should the receivers and transmitters be made tunable? Should the BPSK modem-transceiver group be configured as a normal mode of operations (original plans call for this modem to be used only if the primary system fails)? If multiple frequencies are used, will one set of antennas suffice?

F. SCOPE OF THESIS

The scope of this thesis was to determine potential user communities (military and non-military) of the NPS PANSAT communication system and their associated communication requirements. Areas for investigation included projected users of current commercial and military communications light satellite systems (in use or under development), applicable military and government agencies demonstrating an interest in capabilities offered by the PANSAT communication system, identification of key potential user(s) and required modification(s) to PANSAT's current design to support these user(s). Chapter II discusses lightsats with respect to PANSAT and other commercial and military lightsat systems (past, present and future). Chapter III addresses possible non-military user applications for PANSAT and proposes a new method for rapidly locating downed airmen. Chapter IV addresses a variety of military user applications for PANSAT, while Chapter V addresses PANSAT modifications required to support user applications suggested in Chapters III and IV. Finally, Chapter VI summarizes thesis conclusions and provides recommendations for implementing modifications proposed in Chapter V.

II. BACKGROUND

A. WHY LIGHT SATELLITES?

1. Cost

A new trend is emerging in both the military and the commercial satellite market. This trend is driven by many factors: a need to lower up-front development cost and a need to reduce satellite launch and operations cost. Current U.S. military satellites are too costly to build and launch in an era of tight budgets. According to U.S. Navy Vice Admiral Richard Macke, director of Command, Control, Communication and Computers (C4) for the Joint Chiefs of Staff (JCS) and former Commander of the U.S. Naval Space Command:

> We've got to do space cheaper. One billion dollars for a satellite can't be affordable. One hundred million dollars for a satellite can't be affordable. Military planners may have to settle for fielding satellites with less capability or with less reliability... Moving to small satellites may also be in the cards. Smaller may not be the whole answer, but it's a part. [Ref. 3:p. 2]

The cost required to build, launch and operate a small, medium and large geostationary satellite are $89, $135 and $248 million, respectively, according to James Stuart (a light satellite consultant in Boulder, CO). The average small satellite generally weighs between 500 pounds and 1000 pounds and costs from several million dollars to less than $20 million dollars. [Ref. 4:p. 6] The total system cost for placing a small constellation of LEO lightsats in orbit could cost less than launching and maintaining a single geostationary satellite.

Another significant advantage of lightsats over their heavier counter-parts is that they may be mass produced, thus further reducing satellite system costs. "Many small satellite builders believe the industry is on the verge of mass production of frames with interchangeable payloads." [Ref. 6:p. 7] Reducing the satellite's size and placing it into LEO not only lowers production and launch cost but reduces the

power required to transmit and receive from the satellite, when compared to a geostationary satellite. This power reduction is due to the shorter distance a signal must propagate to reach a lightsat in LEO (500-1000 km for a LEO satellite vs. 40,000 km for a geostationary satellite). Along with reduced transmit power comes a reduction in the size and power of ground station equipment required to communicate with the satellite. These reductions can result in significant savings to satellite system users and operators.

Many hurdles remain before lightsats become common place in the satellite market. Small satellites will not proliferate in Europe, for example, without a suitable rocket, and rocket builders will not invest in new launchers without proof of adequate demand [Ref. 5:p. 6]. Today, most lightsats ride into space as a secondary payload, and are placed into a predefined orbit consistent with the primary payload's mission. While piggy-backing as a secondary payload can substantially reduce launch costs, predefined orbits are generally not optimized for the lightsat. Mass and volume restrictions placed upon the lightsat as a secondary payload can further complicate satellite design and development. Massive, potential cost savings will be a key factor in overcoming today's obstacles to fully realizing the benefits available from lightsats.

2. Utility

Due to reduced weight and volume, a small constellation of communication lightsats could be placed into orbit by a variety of launch vehicles, rapidly providing increased communications capability to any location in the world. This scenario assumes that a constellation of lightsats are preconfigured for contingency purposes. These lightsats would always be on standby to provide or augment regional communications in the event of natural disasters, military special operations or other emergency type situations.These lightsats would be stored fully integrated with their

launch vehicle. Appendix A outlines a variety of potential lightsat launch vehicles within the U.S. launch vehicle inventory.

Military operations in remote regions of the world often suffer initially due to a lack of well-coordinated communication links back to their controlling headquarters for command and control as well as for logistical support. In the early days of the U.S. military build-up in the Middle East, demand for satellite communications outstripped the capability of the U.S. satellites in the area. "We found ourselves in a very tenuous position in the early days, until we could get satellite constellations optimized." - Air Force Brig. Gen. William Jones, deputy chief of staff for requirements at the Air Force Space Command. [Ref. 7:p. 36] Many military commanders expressed concerns that their forces would be denied the use of U.S. military satellites during war because high ranking users - such as the U.S. President and intelligence agencies - would exhaust the satellite's limited capabilities. These commanders maintained that tactical forces should have their own communications and surveillance satellites, which other users could not preempt. [Ref. 8:pp. 4, 21] Having a constellation of communications lightsats ready to launch would significantly augment command and control as well as logistics capabilities in the early part of a military build-up and/or operation.

3. Function

The architecture for relaying communications by satellite first appeared in 1969 when the U.S. Army launched the Courier satellite. This satellite orbited at low altitudes (under 1000 km), received data, and stored it in memory. When it moved within view of a ground station, the satellite transmitted the stored data. This type of architecture permits the use of a low cost launch vehicle due to low altitude orbits. The satellite cost is also lower due to the wider antenna beam width required to illuminate the Earth, which reduces the satellite antenna size and stabilization

requirements. Station keeping is usually not required. The principal disadvantage with this architecture is its long access time and transmission delay -perhaps hours- waiting for the satellite to pass into view of a user ground station. The long access time is attributed to the time required to track, locate and establish synchronized communications with the satellite as it makes each orbital pass. [Ref. 9:p. 13.1.1]

B. WHY PANSAT?

1. Overall Objectives

a. Maximize Opportunities

The primary mission of PANSAT is to provide opportunities to enhance the education of student-officers at NPS. Students are rigorously involved in nearly every aspect of the PANSAT design, fabrication and testing processes. PANSAT will provide a space-based platform for conducting a variety of on-orbit experiments. PANSAT is designed as proof of concept for a quick reaction, low cost, store-and-forward, packet radio, digital communication system. Figure 2 provides a pictorial representation of PANSAT's primary objectives.

b. Demonstrate Feasibility

PANSAT is being designed to demonstrate the feasibility of a simple, low-cost, communications satellite with over-the-horizon, store-and-forward, packet-radio, digital communications. PANSAT will also demonstrate spread spectrum communications on a small, relatively inexpensive satellite with LPI and LPD. PANSAT will employ an inexpensive, possibly portable, ground station (P.C. based with minimal specialized equipment).

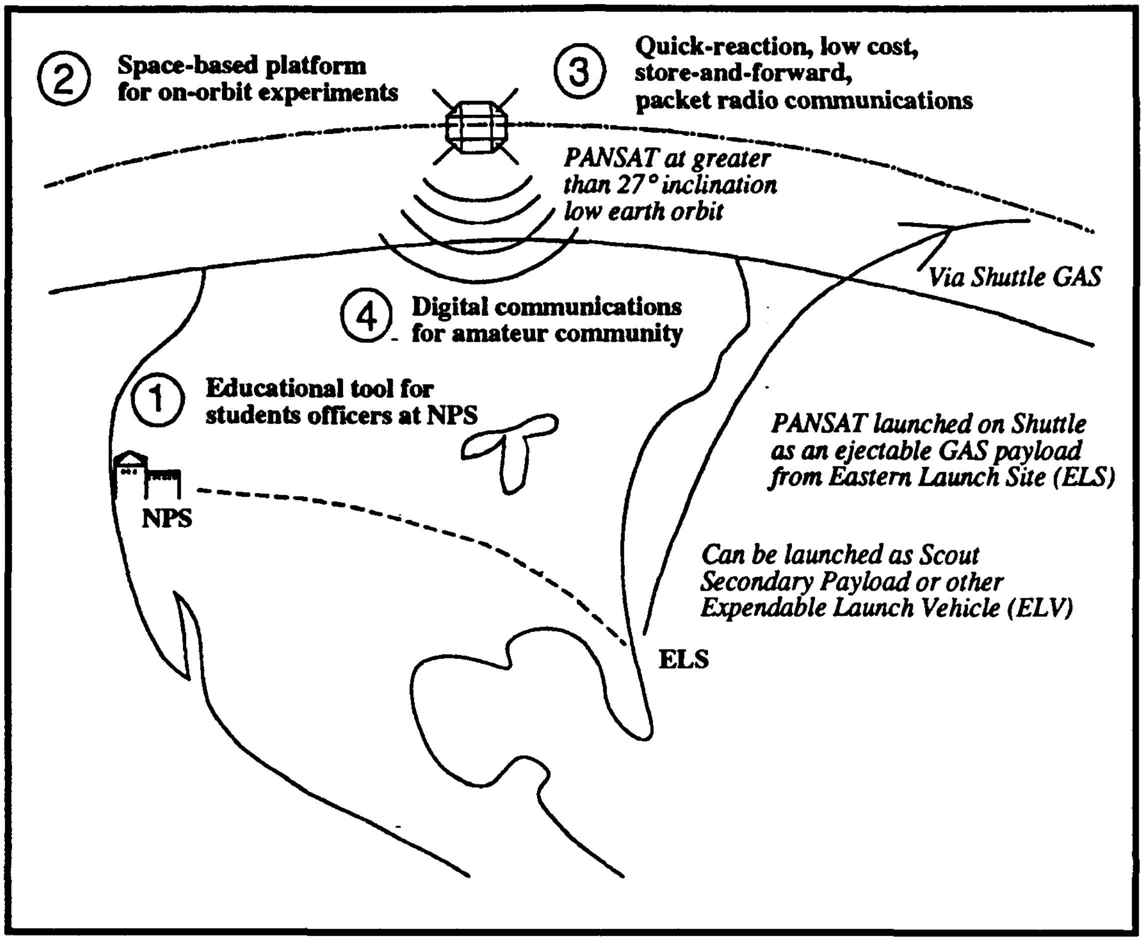

Figure 2: PANSAT objectives [Ref. 2]

2. Engineering Objectives

Using the amateur community as the user base, PANSAT will be one of the first (if not the first) LEO satellites to employ spread spectrum packet radio communications. PANSAT may also provide an experimental platform to research an innovative method of measuring solar cell parameters and sensing sun direction from differing solar cell voltages.

3. Design Objectives

With a planned weight of only 68 KG (150 lbs) and a diameter of 19 inches, PANSAT is designed to fit inside a shuttle Get-Away Special (GAS) canister as well

as numerous other Expendable Launch Vehicles (ELV). Additionally, it and will demonstrate a low-cost design using military and selected radiation-hard components.

PANSAT's communication payload specifications require PANSAT to operate in a full duplex, direct sequence spread spectrum mode with a center frequency of 437.25 MHz and data rates of 1200 and 2400 baud or higher.

4. System Design Timeline Objectives

PANSAT has several milestones to facilitate the timely development and integration of its various subsystems into a cohesive, well functioning satellite. To prepare for a proposed, late 1995 launch date, the following system design time line has been established:

- Oct. 1992 - System Design Review
- Feb. 1993 - Finalize Design Plan
- Mar. 1993 - Critical Design Review
- Mar. 1994 - Begin Integration Testing
- Apr. 1995 - Hardware Flight Delivery Date

Design modifications discussed in Chapter V of this thesis must be further reviewed to determine absolute power, weight, volume and communication systems compatibility with PANSAT prior to the February 1993, the design finalization review.

5. Funding Objectives

PANSAT is a low cost program on a limited budget. The Army Space, Technology and Research Office (ASTRO) is supporting PANSAT and several other academic efforts at NPS. PANSAT has received approximately $150,000 in funding to date and has a total projected future funding of $418,000 from ASTRO and NPS. Implementing modifications suggested in Chapter V of this thesis may require additional sponsors and/or funding sources.

C. OTHER UHF LIGHT SATELLITES

1. Civilian

The scramble to build lightsats and related systems represents a shift by the space industry to no longer ignore this potentially lucrative field.

> As the customers emerge for small satellites, we see the big guys trying to move in and build them, said Jeff Manber, Executive director of the Space Foundation, Washington. Jill Stern, a partner with the Washington law firm Miller and Holbrooke said... what was once seen as an off-beat garage type of business by amateurs making tiny things has now changed.[Ref. 4:pp. 6,12]

Table 1 lists the most recently proposed commercial communication satellite systems. These systems (often referred to as "Big Leo" systems for the large numbers of satellites employed in multiple orbital planes in low to medium altitude orbits) are designed to open the way for handsets that would be only slightly more powerful than current cellular telephones.

Of the systems noted in Table 1, Aries, Orbcomm and Starsys will use a simple repeater/bent pipe configuration while Globalstar, Odessy, and Ellipso will use Code-Division-Multiple-Access (CDMA) spread spectrum as well as simple repeater/bent pipe configurations.

> They would link a mobile user with a gateway Earth terminal that would connect into a public telephone system to reach the intended recipient. A user handset would transmit to the satellite at L-Band (1.6 GHz) and receive at S-band (2.5 GHz). Communications between satellite and gateway stations would be at C-band (5-66 GHz) or K_a band (30 GHz). [Ref. 10:p. 61]

The major difference between Iridium and other competing systems is that the Iridium system will have cross links between satellites and thus be capable of bypassing terrestrial telephone and cable services, linking the calling party to the gateway station nearest the party being called.

TABLE 1: PROPOSED COMMERCIAL "BIG LEO" SYSTEMS

Developer	Orbit	#Sats	Inc.	Purpose
Constellation Communication Corp's "Aries" [Ref. 10:pp. 60,61]	635m	48	90°	World wide, simple repeater/bent-pipe communications (uses 4 orbital planes)
Ellipsat's "Ellipso" [Ref. 10:pp. 60, 61]	HEO	24	63.4°	World wide, spread spectrum (CDMA) communications satellite in a Highly Elliptical Orbit (HEO)
Leosat's "Starsys" [Ref. 11:p. 2]	LEO	24	?	World wide, relay of short messages
Loral & Qualcomm's "Globalstar" [Ref. 4:pp. 6,12]	750 nm	24-48	50°	World wide, spread spectrum (CDMA) communications satellite; can locate a user to within 1000 feet
Motorola's "Iridium" [Ref. 12:pp. 1,36]	500 nm	66	90°	World wide, mobile, public telephone service, TDMA, relay stations on L-band
Orbital's "Orbcomm" and "Starnet" [Ref. 13:pp. 6,10]	LEO	24	?	World wide relay of short messages such as distress signals
Russia's "SmolSat" [Ref. 14:p. 15]	LEO	36	?	World wide, store-and-forward medical information
TRW's "Odessy" [Ref. 10:pp. 60,61]	6,400 nm	12	55°	World wide, spread spectrum (CDMA) in Medium Earth Orbit (MEO)

The frequency spectrum for this new kind of communications satellite service was authorized at the1992 World Administrative Radio Conference (WARC-92) in Spain. WARC-92 authorized two frequency spectrums centered at 1.6 GHz. (L-band) and 2.5 GHz. (S-band) for systems capable of providing both voice and high speed data service. The conference also authorized a frequency spectrum for

little LEOs in the very high frequency (VHF) and ultra high frequency (UHF) bands. [Ref. 10:p. 60]

2. Military

At the direction of the Defense Advanced Research Projects Agency (DARPA) two UHF light satellite systems were developed, flown and tested. Each of these systems were built by Defense Systems Incorporated (DSI). These systems each proved the functional utility of the lightsat concept for the military in a variety of ways. The first of these two systems was the Multiple Access Communications Satellite (MACSAT) and the second was Microsat.

a. MACSAT

In May, 1990, two 136 pound MACSATs were launched by a scout ELV at Vandenburg AFB into a 400 nautical mile, polar orbit. Figure 3 depicts a MACSAT in its deployed configuration. MACSAT records data or imagery messages from a transmitting station on the ground with a 1200 or 2400 baud data rate and rebroadcast the message later when the spacecraft passed over the recipient. Even small Multi-Spectral-Image (MSI) files (<32 kilobytes) were successfully transmitted to the satellite (uplinked) and received from the satellite (down linked) during system tests. MACSAT is stabilized by a 20 foot gravity gradient boom with a five pound tip mass [Ref. 15:pp. 161-230]. With 1.2 megabytes of mailbox RAM, MACSAT provides store-and-forward digital data communications to a variety of military users.

The Marines used MACSAT's store-and-forward capability during Operation Desert Storm for the ordering of aircraft parts. [Ref. 16:p. 12] Two MACSAT user ground terminals were positioned in the Middle East and one in Spain. In a November 1990 interview, Dr. William Howard, former Technical Director of the Naval Space Command, stated that

> the military utility of the Defense Advanced Research Projects Agency MACSATs (136-pound communications satellites) to the U.S. Marine Corps in the Persian Gulf region as part of Operation Dessert Shield has come as a surprise to many observers. The Marines were quick to seize on the utility of the MACSATs to support their logistics in the Persian Gulf. [Ref. 17:p. 19]

The MACSAT command ground station, once operated by Defense Systems Incorporated (DSI), is now under the direct control of the U.S. Navy and has been moved from Dalgren, VA to Point Mugu, CA.

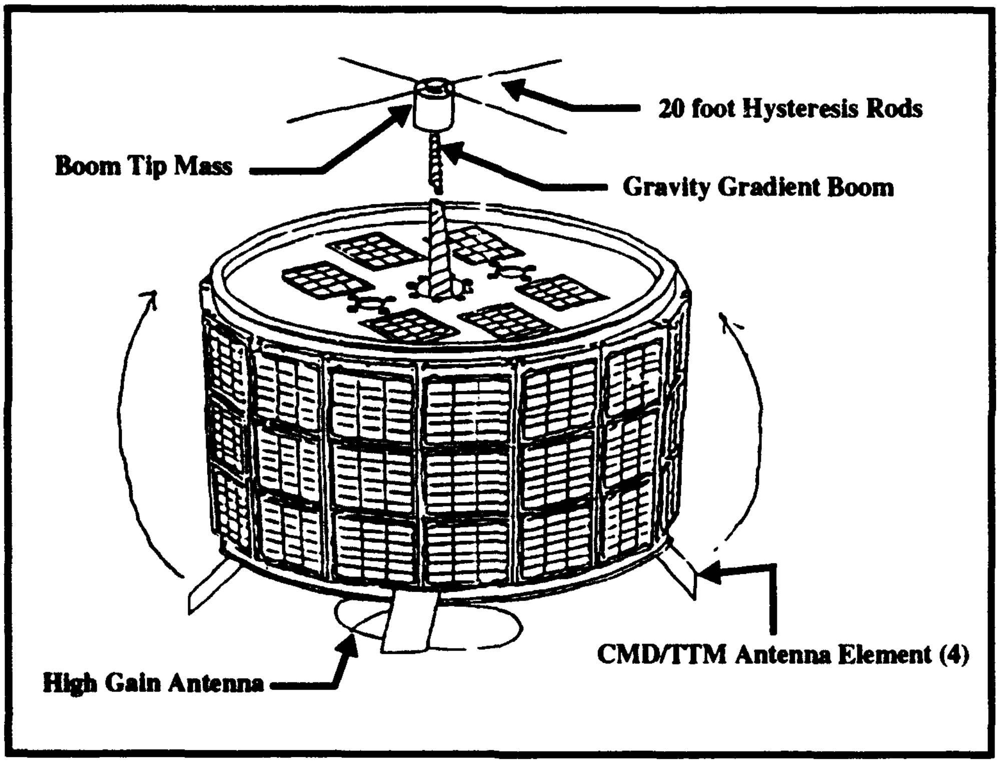

Figure 3: MACSAT design [Ref. 15:p. 1]

MACSAT continues to provide an important communications link for U.S. Navy personnel in Antarctica. These personnel are able to keep in touch with their superiors in New Zealand and California via a standard UHF military radio, lap top PC, a DSI frame formatter and communications software developed by DARPA. [Ref. 18:p. 10]

b. Microsat

Microsats are a group of seven lightsats built by Defense Systems Inc. for DARPA to demonstrate the use of small, UHF communications satellites for the U.S. military in tactical land and naval operations. Figure 4 shows the Microsat constellation in a polar orbit.

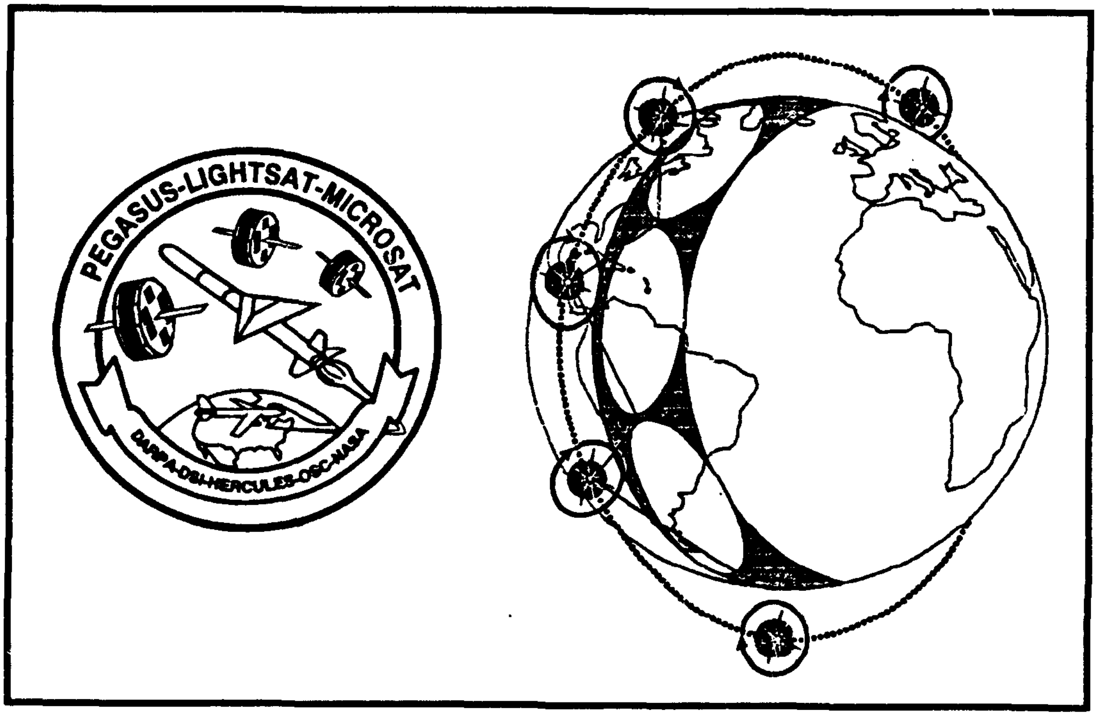

Figure 4: Microsat Logo and Constellation [Ref. 20]

Plans had called for the seven satellites to be spaced evenly along their orbit so any given location in central Europe would have continuous coverage. Ideally, each Microsat would form UHF voice and data "bent pipe links," providing real time relay between two users within the satellite's view. The Microsats used an analog system for voice communications and a digital regenerative transponder for messages, facsimile and low data rate images. Each Microsat had 32 kilobytes of RAM for limited store-and-forward purposes. [Ref. 19:p. 3] Each satellite was spin-

stabilized at three revolutions per minute and was also equipped with a cold gas thrust/maneuver system for initial positioning and station keeping operations.

In July, 1991, a Pegasus carried these seven, 50 pound satellites into a near polar orbit inclined at 81 degrees. The Pegasus payload faring malfunctioned, causing the lightsats to deploy far short of their intended 389 nautical miles LEO orbit. The orbit achieved ranged from 192 to 245 nautical miles. Due to the Pegasus malfunction, the lifetime of the Microsat constellation was reduced from three years to six months. At the planned orbit, the Microsats would have been arranged to provide nearly continuous communications for designated users. As one Microsat moved out of a user's range, another would have moved into place, with a one minute gap between coverage. [Ref. 21:pp. 4, 21]

Even though the orbit of each Microsat eventually decayed, DARPA successfully tested the transponders and the limited store-and-forward capabilities of the Microsat constellation with the Air Force, Army and Navy forces in the United States and Panama.

c. *Future U.S. Military Lightsats*

The U.S. Navy and Army each plan to field lightsat satellites later this decade to provide extra communications in tactical military situations as diverse as a submarine beneath the Arctic or a land battle in a remote site. Rear Admiral Thomas Betterton, the former Assistant Commander for Space and Technology at the Navy's Space and Naval Warfare System's Command, said that

> the Navy plans to field a constellation of six UHF satellites in polar orbits, and the Army is developing a small EHF communications satellite that could be orbited quickly during a war... The Navy's so-called Arcticsat system is intended to provide satellite communications for Navy ships and submarines operating north of 70 degrees latitude. [Ref. 22:p. 22]

Areas north of 70° latitude can not be easily ranged with GSO satellites, making the smaller, polar-orbiting LEO satellites an attractive "gap filler" to provide communications to Arctic bound U.S. Navy submarines.

Currently being designed for the Army is the Multiple Pass UHF Beyond Line of Sight (MUBL) satellite system. MUBL is a spread spectrum, bent pipe satellite system with satellites in 400 nautical mile orbits. This system will use multiple communication paths via ground-based repeaters and space-based relays.

These projects will allow DARPA to assess the usefulness of small satellites for augmenting conventional large communications satellites and to provide the capacity to handle surges in communication requirements.

III. POTENTIAL NON-MILITARY PANSAT APPLICATIONS

A. GENERAL

Current PANSAT designs call for operations only on the assigned amateur frequency of 437.25 MHz. The use of amateur radio frequencies is governed by a complex hierachy of rules and regulations.

> By FCC regulation, no use is to be made of amateur frequency bands by any business, government agency or group other than duly licensed amateurs. These regulations are made to protect AMSAT's (Radio Amateur Satellite Corporation) use of assigned frequency bands. AMSAT can allow other users if system design includes AMSAT inputs. [Ref. 23:pp. 3,4]

Rules and regulations directed at the amateur satellite service are attributed in part to the International Telecommunications Union (ITU), the Federal Communications Commission (FCC) and the International Amateur Radio Union (IARU). ITU member nations meet aperiodically at World Administrative Radio Conferences (WARCs) to consider changes to existing regulations. PANSAT system users must possess an Amateur Extra Class operator license and be in compliance with all appropriate rules and regulations. [Ref. 24:p. F-1] Accordingly, any government employee transmitting over PANSAT's assigned amateur frequencies must be a licensed amateur radio operator. A possible exception to this rule is the use of PANSAT for civil emergency purposes. Additionally, these rules and regulations prohibit the use of amateur frequencies for non-emergency military or commercial purposes.

B. AMATEUR RADIO

1. A Brief History

Around 1914, the American Amateur Radio League (AARL) was organized to establish routes of amateur radio communication and serve the public interest

through amateur radio. Amateurs have served the public in a wide range of emergencies.

> Commercial communications services are often disrupted by power failures or damage that accompanies natural disasters such as earthquakes, floods and hurricanes. Many amateur stations can operate from a car battery... When disaster strikes, amateurs are ready to carry on communications for police, fire departments and relief organizations. [Ref. 1:p. 1-4]

Amateurs have been building and launching communications satellites for over 30 years. OSCAR I (Orbiting Satellite Carrying Amateur Radio), the first amateur satellite, was launched on 12 December 1961. Amateur satellites are categorized as falling into one of four phases [Ref. 24:p. 4-2]:

Phase 1: experimental, short lifetime, LEO ('1961-70);
Phase 2: developmental & operational, long lifetime. LEO ('1972-today);
Phase 3: operational, long-life, high altitude, elliptical orbit (1983-today);
Phase 4: operational, long-lifetime, GSO (future).

The Radio Amateur Satellite Corporation (AMSAT) was founded in March of 1969. AMSAT bylaws state that AMSAT is organized exclusively for scientific purposes to "develop and provide satellite and related equipment and technology useful for amateur radio communications throughout the world on a nondiscriminatory basis." [Ref. 24:p. 3-2]

Amateur packet radio experiments began in Canada in 1978 with the first US amateur packet radio demonstrations following two years later. The AX.25 packet radio protocol was introduced in 1983 when the first amateur digital satellite store-and-forward packet radio communications experiment was conducted in January of 1985. 1987 marked the beginning of amateur radio packet networking expanding from terrestrial to space applications by 1989.[Ref. 25:pp. 2-1: 2-15]

2. Amateur Radio Satellite Users

There are currently over 150,000 licensed US amateurs and an additional 11,000 licensed foreign amateurs. [Ref. 1:p. 1-4] The majority of these amateurs use terrestrial HF and VHF mediums. Only a small portion of amateurs make extensive use of amateur satellite communications.

> If you use satellites for communicating, you're probably more interested in satellites than in communications. As a result, if we continue to pursue evolutionary improvements in current systems, the size of the amateur satellite user community will show only modest growth since the program will continue to appeal to those primarily interested in space activities. [Ref. 24:p. 4-17]

The future of amateur satellites is pointing towards larger, more expensive Phase 4 (GSO) systems as opposed to continuing to update the current Phase 2 and 3 spacecraft. Table 2 provides a cost comparison for Phases 1, 2 and 3. Note that Phase 4 spacecraft are over an order of magnitude more expensive than their earlier counterparts. It is theorized that if the amateur community continues to build only Phase 2 and Phase 3 systems

> the amateur satellite service is likely to see modest growth and a relatively healthy ongoing program over the next 5 to 10 years. However, satellite communications will remain a small minority segment of amateur radio. [Ref. 24:p. 4-20]

A key point is that only a relatively small percentage of amateurs are currently using amateur satellite services. An additional point of interest is that no amateur radio satellite system is currently spread spectrum capable.

PANSAT will limit the number of potential amateur radio satellite users that it services through the use of spread spectrum. The average amateur radio operator has neither the time, resources, knowledge or resolve to equip an amateur radio system for spread spectrum satellite communications. Only those highly motivated

amateurs interested in experimenting with a spread spectrum satellite system will have the determination to undertake such a project.

TABLE 2: AMATEUR SATELLITE CONSTRUCTION COSTS [Ref. 24:p. 4-22]

Satellite	Phase	Cost (1987 $)	Launch Date
OSCAR 1	1	$26	12 December 1961
Australis-OSCAR 5	1	$6,000	23 January 1970
AMSAT-OSCAR 6	2	$15,000	15 October 1972
AMSAT-OSCAR 7	2	$38,000	15 November 1974
AMSAT-OSCAR 8	2	$50,000	5 March 1978
AMSAT-Phase 3-A	3	$217,000	23 May 1980
*UoSAT-OSCAR 9	2	$100,000	6 October 1981
AMSAT-OSCAR 10	3	$576,000	16 June 1983
*UoSAT-OSCAR 11	2	$200,000	1 March 1984
AMSAT-OSCAR 13	3	$385,000	15 June 1988
AMSAT-Phase 4A	4	$2,500,000	Proposed GEO System

*UoSAT (University of Surrey, England Satellite)

3. Additional Amateur Radio Satellite User Contributions

The Defense Advanced Research Project Agency (DARPA) used the ITU's International Radio Advisory Committee (IRAC) to announce authorization for amateurs to begin testing and experimenting with DARPA's Microsats in early 1992.

> In order to conduct a wide range demonstration of the DARPA Microsats prior to re-entry, the Naval Academy coordinated a nationwide Military Affiliate Radio System (MARS) satellite test during early January, 1992. Volunteer MARS stations are well known for their emergency communications capabilities and for handling informal messages between servicemen and their families. With hundreds of stations nationwide, with many active in AMSAT programs, a MARS system test would bring together a large pool of experienced satellite users in a short period of time.[Ref. 26:p. 1]

As a result, almost all the successful Microsat experiments were performed by amateur radio operators. All MARS frequencies are in the military band. Having an experimental DoD satellite operating in the military band does not necessarily prevent amateur radio satellite enthusiast from making use of these systems.

C. AIRCRAFT SEARCH AND RESCUE

The National Aviation Safety Management Office is contained within the Bureau of Land Management. A prime concern of the National Aviation Safety Manager is the timely rescue of downed aircraft survivors.

1. Search and Rescue Satellite Aided Tracking (SARSAT)

SARSAT receivers (flown on two Russian Cosmos satellites and the National Oceanographic and Atmospheric Administration's NOAA-11 satellite) provide the world with a unique type of search and rescue capability to locate downed aircraft that can not readily be found via terrestrial means. The distress signal from downed aircraft originates from an Emergency Locator Transmitter (ELT) which transmits over one of three frequencies (121.5 or 243.0 for older transmitters and 406.1 MHz for newer ones). Appendix C provides an in-depth summary of the SARSAT system capabilities and limitations. Figure 5 depicts the Search and Rescue (SAR) system as it was designed to relay a continuous beacon from ELTs (via satellite) back to SAR forces.

From 1982 until 1988 SARSAT has been credited with saving over 1,150 lives (596 individuals involved in aviation accidents, 506 sailors involved in maritime mishaps and 47 individuals lost on land when their distress signals were relayed via satellite). The US Coast Guard requires all ocean fishing vessels to acquire and maintain a 406 MHz ELT by 1994 (another name commonly used for an ELT is Emergency Position Indicating Radio Beacons (EPIRB)). [Ref. 27:pp. 43,45]

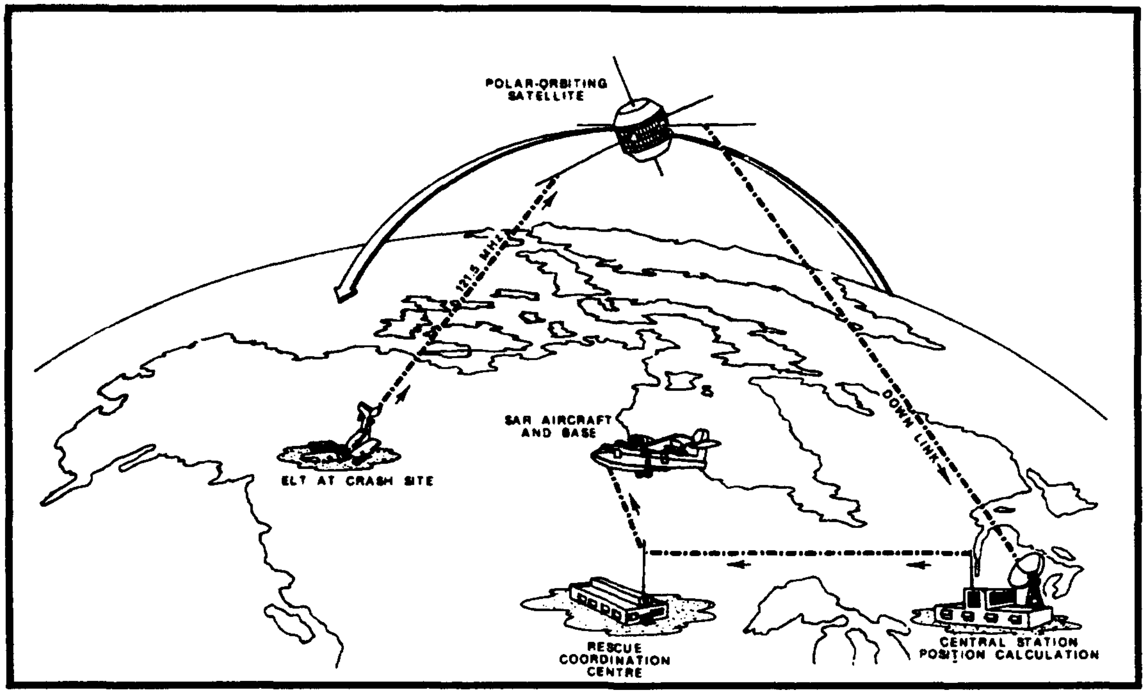

Figure 5: Satellite Aided SAR System [Ref. 28:p. 21-7]

2. Search and Rescue Tracking - PANSAT[1]

Brian Dean, the National Aviation Safety Manager, has suggested that PANSAT could be an integral part of a system to provide a much faster, more reliable way to locate and rescue downed aircraft survivors than the current ELT dependent system. An experimental Global Positioning System Black Box (GPSBB) could be constructed and tested as proof of concept. If successful, a functional version of these GPSBB could replace the current ELTs to provide precise location, time and identity of distressed airmen and sailors.

This GPSBB would contain a GPS module capable of receiving GPS satellite transmissions to determine the downed aircraft's location. Each GPSBB would also contain a transmitter, such as a PRC 90-2 (see Figure 6) capable of

1. Telephone conversation and interview with Brian Dean, National Aviation Safety Office, and the author, 2 June 1990

sending a 243.0 MHz data stream once activated (presumably on impact) to PANSAT. Figure 7 represents a possible Emergency Locator Rescue System (ELRS) simulated exercise conducted between a mobile GPSBB and PANSAT. This data stream would include the downed aircraft's identification, precise location and time of impact. The data stream format from the GPS card could be processed and formatted by a TNC and sent to a PRC 90-2 or a PRC 112 radio for transmission to PANSAT. The data stream would have to be consistent with the AX.25 protocol (or modified protocol) for processing and dissemination by the PANSAT Central Processing Unit (CPU) and communications subsystems.

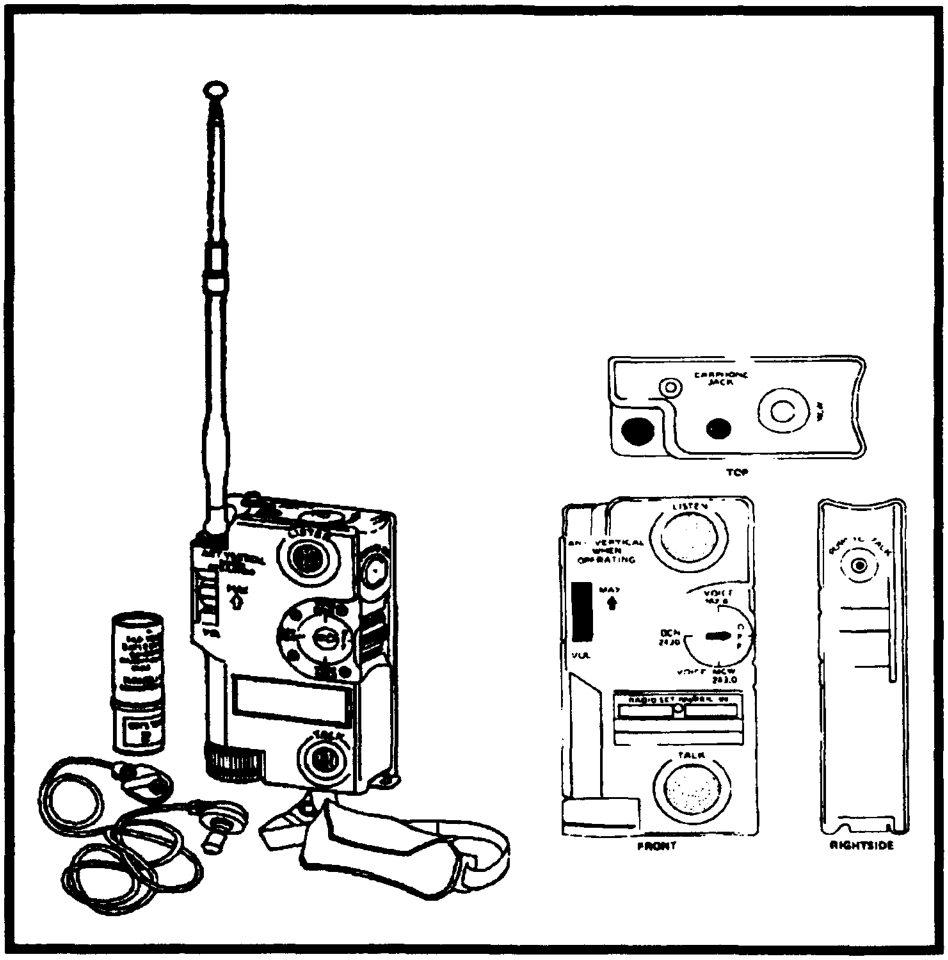

Figure 6: PRC 90-2 Radio [Ref. 29:p. 3-6]

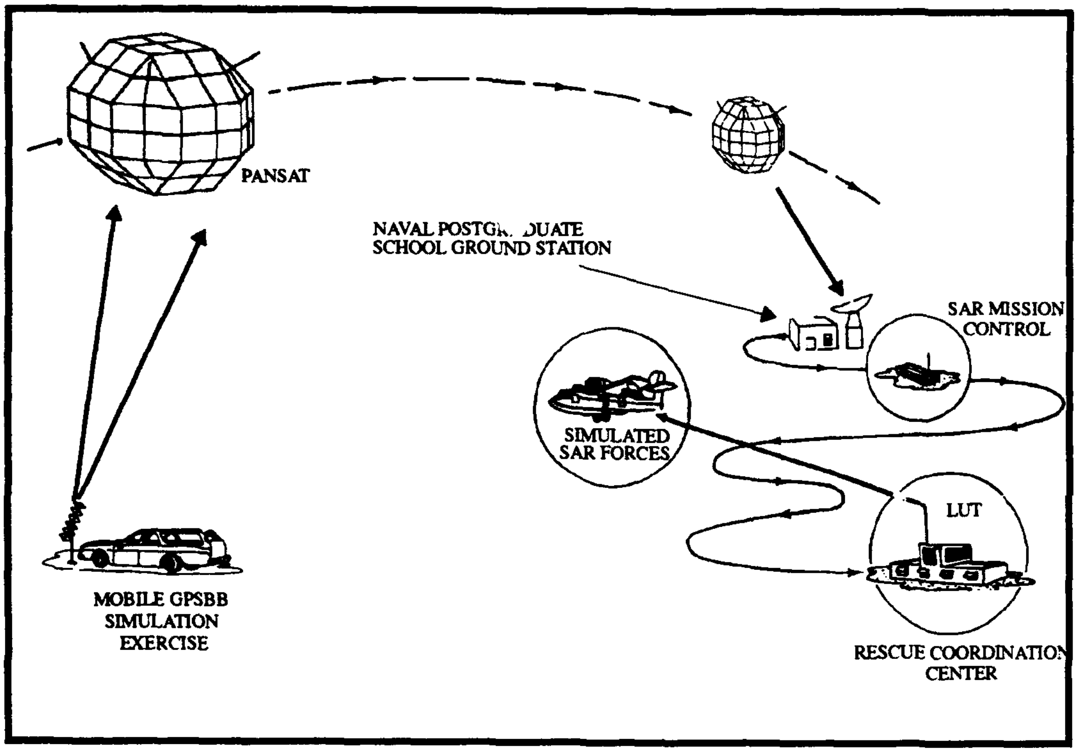

Figure 7: Mobile GPSBB-ELRS simulation with PANSAT

3. Conclusion

The GPSBB-ELRS system could rapidly and accurately provide the downed aircraft's precise location. In cases where the aircraft goes down over water (or involves a distressed merchant or sailor), the GPSBB could be miniaturized to permit the pilot/crew to carry it within their flight jacket (see Figure 8). Since over two thirds of the world's surface area is covered by oceans, the GPSBB may prove even move invaluable in maritime situations.[2]

2. Telephone Conversation and Interview with Robert A. Payne Sr. and the Author, 31 July 1992.

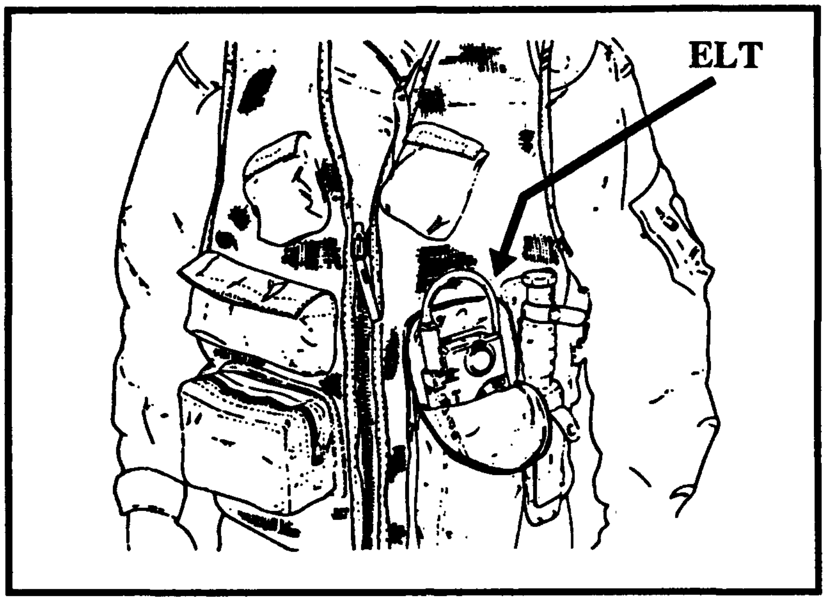

Figure 8: Portable ELT [Ref. 29:p. 2-2]

Using the ELRS concept, multiple tracks on the same beacon could assist in determining whether or not the distress signal is a real emergency or not. If the location of the emitter has moved since the last PANSAT pass, the emitter is "on the move" and the ELT signal is probably just another false alarm.[3]

A modified PANSAT equipped with a passive receiver on 121.5, 243.0 and/ or 406.1 MHz could receive and retransmit the downed aircraft identification and precise location over PANSAT's normal transmission frequency to either the NPS ground station, specially designated user and/or all active system users.

Given the number of lives the SARSAT system has been credited with saving over the past 10 years, the number of lives the potential PANSAT/GPS black box system could save is staggering. PANSAT could provide a means to more rapidly receive and disseminate the identity and GPS derived location of a downed airplane, distressed merchant vessel or otherwise lost or stranded victim.

3. Interview between Paul J. Groce, Kurz Manufacturing Co., and the Author, 10 September 1992.

D. REMOTE FIELD SITE COMMUNICATIONS

The Bureau of Land Management has field teams comprised of over 11,000 people spread out over the 12 western states. Due to resource limitations and remote locations, these teams do not have the ability to communicate with anyone. They do not even have any emergency communications capability. Each team depends upon biweekly "air dropped" resupplies for logistical support. Mr. Dean has suggested the possibility of using and/or modifying a small hand held computer, TNC, and associated UHF receiver/transmitter to enable field teams to use PANSAT's store and forward capability to enable them to communicate with their parent headquarters.

The Bureau of Land Management represents only one of the nine bureaus within the Department of Interior. Each of these bureaus has field work parties and most have requirements to communicate from the field to their headquarters. The possibility exits for PANSAT to provide an important service to each of these teams. However to use PANSAT, they would have to become licensed amateur radio operators.

E. THE DEPARTMENT OF AGRICULTURE

The Department of Agriculture has long had a need to receive daily responses from sensors located all over the Rocky Mountains. These are remote locations where it is not practical and/or possible for personnel to gather such information.

> Since 1978, the U.S. Department of Agriculture's Snotel system has used meteor burst rate to relate snow cover, temperature and river level data from about 550 remote sensors in the Rocky Mountains. In Alaska, meteor burst is used by the Air Force for remote pipeline monitoring and for obtaining remote weather data at isolated air strips...The maximum distance a single meteor burst signal can travel is approximately 1200 miles, and is a function of the meteor trail height and the curvature of the earth. Transmitters using meteor

> burst must use relatively high power (several hundred watts...) and receivers must be very sensitive to enable continuous reception of data while the signal weakens from the vanishing meteor trail. [Ref. 30:p.]

Instead of using meteor burst transmission, these sensors could potentially be programed and equipped to transmit their data when the senor was in PANSAT's field of view. This data could be stored and later retrieved from PANSAT by the Department of Agriculture's master ground station. Questions ranging from what frequency to use to other technical and regulatory challenges would have to be addressed before PANSAT could adequately support this mission.

F. FEDERAL EMERGENCY MANAGEMENT AGENCY

The Federal Emergency Management Agency (FEMA) coordinates efforts of the National Guard, Army Special Forces Command (ARSOF) and other federal agency disaster relief efforts. Amateur radio operators are often the first to attain long haul communications immediately after the occurrence of natural disasters. FEMA encourages amateur radio support in providing a means to augment or replace damaged terrestrial communications after natural disasters such as hurricanes, typhoons, tornadoes and earthquakes. PANSAT would be available to provide a vital communication link to communities temporarily isolated by a natural disaster such as Florida's August 1992 Hurricane Andrew. These communication links could be used to coordinate emergency relief efforts as well as a host of other requirements.

IV. POTENTIAL MILITARY APPLICATIONS OF PANSAT

A. GENERAL

With PANSAT's original design plan, the only military personnel authorized to use PANSAT are those who are licenced, amateur radio operators. This chapter looks at potential military users. In order for PANSAT to work well with its users, it is imperative that these users become intimately involved with the satellite communications protocol development. These protocols should be developed with primary user needs given foremost consideration. Facilitating a close working relationship between system designers, builders and users will assure the most user-friendly and capable communications system is developed.

1. Use of Military Frequencies

A PANSAT approved to operate within the military's 225-400 MHz frequency band could support non-tactical military users similar to the way MACSAT supported U.S. Marine logistical traffic throughout much of Operation Desert Storm. A PANSAT with real time, bent pipe communications capabilities could be extremely useful to the tactical military.

2. Assumptions

To facilitate the exploration of PANSAT possibilities for military users, several assumptions have been made. The first assumption is that military UHF frequencies will be approved for PANSAT use. This assumption holds in all cases addressed in this chapter and is elaborated on more fully in Chapter V of this thesis. The second assumption is that PANSAT will provide an experimental store-and-forward capability on UHF military frequencies. The third assumption is that PANSAT will provide an experimental, Satellite Communications On The Move (SOTM) capability to UHF military users. The second assumption is assumed valid

for non-tactical military users while the third assumption is assumed valid for both tactical and non-tactical military users. This chapter is not intended to be a comprehensive listing of all possible military users of PANSAT, but rather a sampling of various communities.

3. Spread Spectrum Limitations

Direct sequence, Pseudo Random Noise (PRN) code spread spectrum systems do not work well in areas saturated with multiple users unless numerous PRN codes are used. This situation is improved by separation of users having the same PRN codes, however, another problem may occur: the near-far problem. The near-far-problem results when a nearer user transmits at the same approximate time a far away user transmits. In this situation, the signal that gets through is the stronger of the two. Signal strength is a function of many variables. However, transmission power and free space loss, which is inversely proportional to the square of the distance between the user and the satellite, combine to form two of the most influential factors. Thus, in an area saturated by spread spectrum system users with the same PRN coding sequence, a significant amount of interference could result (the near-far problem).

Another draw back to spread spectrum systems is a reduced information transfer rate as compared to non-spread spectrum type systems. The LPI and LPD that spread spectrum systems gain results in reduced data rates. There are no UHF spread spectrum receivers/transmitters in the current Army inventory.

B. ARMY SPACE RELATED AGENCIES

The three primary Army agencies investigated were the Army Space Technology and Research Office (ASTRO), the Army Space Institute (ASI), and the Army Space Command (ARSPACE).

1. ASTRO - Technological Demonstrations

ASTRO invests time and resources into promising technologies for the future. ASTRO has been instrumental in providing resources and support necessary to permit the successful development of PANSAT as an experimental satellite providing a maximum amount of educational opportunities to NPS student-officers.

2. ASI - Conceptual Demonstrations

ASI is interested in military, UHF, LEO satellite communications that are both spread and non-spread spectrum, digital and analog. PANSAT as a possible resource for interacting with a new program of doctrine-guided technology development. This program is the Army Training and Doctrine Command's (TRADOC's) Battle Lab. During the cold war, it took 10 to 15 years to develop a weapon system from concept to operational fielding. One of the primary focuses of the TRADOC's Battle Lab is to cut acquisition time from 10-15 years to 4-6 years.

Battle Labs are designed to

- provide a streamlined institutional, low cost means for defining requirements;
- furnish an organized, established setting for soldiers to experiment with new ideas and technologies;
- allow for refining user requirements with the developer;
- enable examination of emerging doctrine, training technologies and leadership methods, organizations and material; and
- create a responsive institutionalized link between technological opportunity and war fighting concepts.

Battle Labs may develop capabilities for a force projection Army that begins where battle appears to be changing and encourages experimentation via simulations or virtual prototyping to determine technology insertion or new requirements. The Command and Control (C^2) Battle Lab is one of six labs in TRADOC which test new technologies to gauge how well they provide for Army communications needs. [Ref. 31:pp. 32, 34]

3. ARSPACE - Performs Tactical Demonstrations

ARSPACE introduces new technologies to tactical units in field training environments to assess the utility of these systems. ARSPACE is fundamentally interested in many aspects of LEO, UHF, military communications as well as many others. ARSPACE planners are particularly interested in experimenting with LEO lightsats which offer a variety of capabilities such as:[4]

- Store-and-forward;
- Bent Pipe and/or regenerative transponder for SOTM;
- Spread verses non-spread spectrum;
- Assured access (guaranteed system availability);
- Ability to command the satellite into switching modes of operation;
- Voice transmission capabilities;
- Satellite development and operational costs; and
- Compatibility with existing military UHF systems (e.g. LST-5 radios and AN/PSC-3 (TACSAT) radios).

For non-spread spectrum operations, PANSAT must be compatible with the LST-5 and the AN/ PSC-3 radios. These radios employ 5 kHz as well as 25 kHz selectable bandwidths. By 1994 all military UHF radios must modified to provide 5 kHz bandwidth and by 1996 must all be Demand Assigned Multiple Access (DAMA) compatible.

Figure 9 depicts a lightweight, deployable UHF SATCOM suitcase system (fully equipped with a LST-5C, an encryptor and ancillary equipment to provide worldwide wide and narrow band voice and data communications). This figure also depicts a portable computer (called a GRID computer) and lightweight, UHF antenna (manufactured by Dorne and Margolin, Incorporated). Table 3 depicts the distribution of AN/PSC-3 and LST-5 UHF radios in the U.S. Armed Forces.

4. Telephone conversation and interview with CPT J.C. Chin, ARSPACE, and the author, 14 August 1992.

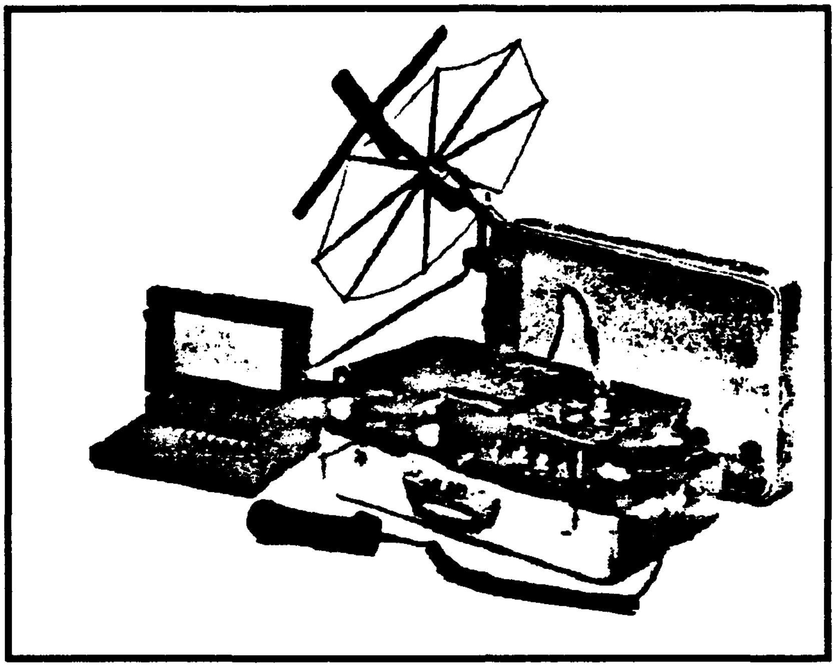

Figure 9: Light, Deployable, UHF SATCOM Suitcase [Ref. 34:p. 2]

TABLE 3: AN/PSC-3 AND LST-5 UHF RADIO DISTRIBUTION [Ref. 32]

Radio	Army	AF	Navy	MC	CINC	Other	Total
AN/PSC-3	477	61	160	148	56	6	908
LST-5B/C	524	817	170	25	74	1390	3000

C. LIGHTSAT COMMUNICATIONS REQUIREMENTS

Operation Desert Storm provided the opportunity for the Army to begin realizing the full value of satellite communications for the tactical commander in a fast paced, ever changing combat environment.

> Small satellites in low Earth orbit can provide voice channels to tactical units deployed over large areas; these channels enhance the communications that are required for maneuver warfare. A low Earth orbit allows the use of low-power transmitters and simple antennas that are small and lightweight. Low power transmissions are difficult to locate, so the risk of exposing positions by communication is greatly reduced. [Ref. 33:p. 1]

LEO satellites should allow for lower power transmitters and smaller, lightweight antennas for the user than GSO satellites. However, this is not always the case. Satellite antenna gain and transmission power are two important factors determining the required user transmission power, antenna size and pointing requirements.

1. Fast Moving Combat Scenarios

The offensive mobility demonstrated during the Army's 24 Infantry Division (Mechanized) Desert Storm operations resulted in tactical units moving as much as 100 kilometers per day. [Ref. 31:p. 15] Standard terrestrial communication systems could not keep abreast of this fast pace to provide adequate communication links between forward deployed units and their associated headquarters.

> Prior to Desert Storm, the low priority of the tactical users at theater and below resulted in minimal use of MILSATCOM for peacetime training or operational situations. In Desert Shield/Storm, the tactical user priority was recognized and MILSATCOM service was provided from all available resources. However, due to the extensive satellite communications requirements, MILSATCOM and commercial services could not satisfy the multitude of requirements.... Intra-theater satellite communications were especially important because of the vast operational areas in which there did not already exist a communications infrastructure.... [Ref. 35:pp. 1,3]

A possible measure of effectiveness for a SOTM system is the ability to communicate on a tactical vehicle's UHF radio to another tactical vehicle's UHF radio over distances spanning from Washington DC to Ohio. SOTM is receiving a considerable amount of attention and R&D study.

2. Deployment of Special Teams[5]

The 106th Signal Brigade (stationed in Panama) is frequently tasked to support multiple deployments of small teams throughout South America. These

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5. Telephone conversation and interview with Major David Quals, ARSPACE, and the author, 16 May 1992.

teams seldom have the priority to obtain access to satellite transponder frequencies nor do they have the assigned assets to allow deployed forces to maintain communication links with their headquarters in Panama. For these teams, PANSAT would be a welcomed asset.

The 6th Infantry Division successfully tested both MACSAT and Microsat systems when they deployed Engineer and Special Forces Medical Teams to the Philippines in 1991. These teams used one of the two orbiting MACSATs to communicate with their headquarters in Alaska. MACSAT communications proved to be more reliable than Autovon. The Microsat constellation was used to provide real time communications with forces deployed in country.

3. Civil Relief Operations

Quite often teams from the Army Corps of Engineers and Army Medical Service Corps are sent on missions into remote areas where no terrestrial means to communicate with their headquarters exist. These users do not have the priority to gain access to FLTSATCOM or TACSAT channels and are too far away from supporting US Embassies to establish viable communications channels. PANSAT could provide a reliable communication link between deployed forces and their headquarters. Enhanced communications via PANSAT could improve civil relief operations, mission planning and execution.

D. SPECIAL OPERATIONS UNITS

Many lower level military users are given missions without the priority or means to establish and maintain communications with their headquarters. Other users may have logistical and / or routine maintenance requirements which could be automated through the use of a system like PANSAT.

While tactical military *command* requires real-time communications, tactical *control* requirements may be satisfied by a satellite store-and-forward systems as

demonstrated by MACSAT during Operation Desert Storm. Store-and-forward satellite systems could also provide communication support for special operational units from the Delta Forces, Navy Seals, Army Ranger Regiment, Civil Affairs Battalions, Psychological Operations units and ARSOF. These units have missions which do not necessarily require real time reporting of information.

Many Special Operations Units communicate with their higher headquarters on a routine basis. Teams from the 1st Special Forces have been able to satisfy their communication requirements of passing situation updates to higher headquarters several times a day using one of the two orbiting MACSATs last year. KG84 encryption devices were used to encrypt signals before transmitting to MACSAT and to decrypt messages after downloading. [6]

Other possible special forces implementations of PANSAT include providing company through group commanders an administrative/intelligence net for non-critical traffic. The present configuration of ARSOF relies heavily on TACSAT to exchange critical message traffic. Removing non-critical information from this net would ease the burden on over-utilized real-time systems such as TACSAT. PANSAT could be more reliable than HF Multi-channel systems fielded to provide a means to reduce TACSAT system usage. Because ARSOF does not rely exclusively on a single communications medium, the additional capability offered by PANSAT would serve to reduce usage or replace other systems which are less reliable and/or more difficult to obtain assured access to. [7]

ARSOF has mission requirements to conduct a wide range of missions in all types of terrain and environments. Command and control is supported by numerous communications systems using HF, VHF, UHF and SHF mediums. The backbone

6. Telephone conversation and interview with Maj. David Quals, ARSPACE, and the author, 16 May 1992.
7. Conversation and interview with SFC Daniel Barringer, USA ARSOF, Ft. Bragg, NC, and the author, 15 September 1992.

of ARSOF communications is HF-AM using analog burst devices (often with encryption). ARSOF units work for the Commander-In-Chief (CINC) through theater level tactical commanders and can be tailored to support any commander at any level. PANSAT could prove effective in supporting ARSOF in most Primary Missions and Collateral Activities.

ARSOF Primary Missions:

- *Unconventional Warfare*- WWII, Vietnam, with limited applicability to Operation Desert Storm (ODS);
- *Direct Action*- Grenada, Panama's Operation Just Cause (OJC), ODS;
- *Special Reconnaissance*- Strategic, operational and tactical in Grenada, OJC and ODS; and
- C*ounter-terrorism*- ongoing support of CINCs.

ARSOF Collateral Activities

- *Humanitarian Assistance*- OJC, post ODS (Kurds), and disaster relief efforts (Florida's August 1992 hurricane Andrew);
- *Counter-narcotics* - ongoing;
- *Security assistance*- ongoing; and
- *Search and Rescue*-ODS with respect to downed air crew members and peace time efforts (natural disasters: earth quakes and hurricanes).

Because many of these missions do not rely heavily on real-time reporting requirements, a system such as PANSAT would be invaluable in circumstances where no other reliable communications medium is readily available.[8]

E. U.S. COAST GUARD

The Coast Guard has buoys positioned up and down both the Atlantic and Pacific coasts of the United States. The health status of each of these buoys is checked by physically inspecting each buoy. The buoy health status includes checking each buoy's battery charge and light bulb status. Each buoy contains seven light bulbs. There is a desire to centralize and automate the monitoring of buoy

8. Conversation and interview between SFC Daniel Barringer, USA ARSOF, Ft. Bragg, NC, and the author, 16 September 1992.

health status. A small, GPS equipped transmitter could be attached to each buoy to routinely send out buoy location, battery and light bulb status to PANSAT. That information could then be downloaded to a buoy control center.[9]

F. NAVAL SUPPORT FORCES ANTARCTICA[10]

The Navy conducts research work for the National Science foundation in support of the U.S. Antarctic program. Many scientific missions could be facilitated by PANSAT's store-and-forward capability. Scientist deployed to Antarctica have used transponders on a variety of satellites:

- the Lincoln Experimental Satellite-9 (LES-9) at 303 MHz
- the International Maritime Organizations C (INMARSAT-C) Satellite

As noted in Chapter II, MACSAT also supports the U.S. Antarctic Program.

G. U.S. NAVAL ACADEMY

The U.S. Naval Academy has been an active participant in amateur satellite communications experiments as well as DARPA's Microsat program.

> During the last two years the U.S. Naval Academy has performed a number of satellite communications experiments including tests with a packet radio network for communications with its boats during the summer cruises along the East Coast. The Academy is fortunate to have obtained the 12 meter dish antenna from NASA in 1989... During the life of the Microsats, periodic beacons on the satellite uplink frequency were relayed to Annapolis via any [Microsat] satellite that was in view. [Ref. 36:p. 2]

The U.S. Naval Academy has demonstrated that its students will maximize utility for every satellite communications system made available.

9. Telephone conversation and interview with CDR James John, Coast Guard Research and Development Center, and the author, 2 June 1992.
10. Telephone conversation and interview with LTCDR Chris Rhone, Naval Support Force Antarctica, and the author, 11 September 1992.

V. PROPOSED PANSAT MODIFICATIONS

A. GENERAL

Since 1988 NPS has been engaged in developing PANSAT. Due to the difficulty in obtaining authorization for UHF military frequencies, NPS turned to the amateur radio community for frequency authorization/allocation.

While conducting research for this thesis, it became clear that unless PANSAT was modified, the only possible applications of PANSAT would be those accessible *only* to properly licensed, amateur radio operators. In a 19 August 1992 letter to the Chair of the NPS Space Systems Academic Group, Dr. Rudolph Panholzer, Robert Bruninga, Director of the U.S. Naval Academy's Satellite Earth Station Facility, wrote:

> we are very excited about your PANSAT, but I personally feel that very few amateurs will actually use it. Even the leading edge spread-spectrum experimenters that I know will talk a blue streak about how neat it is, but they will just keep dabbling in more and more digital signal processing. Many will work hard to get a signal into or out of PANSAT, but once having done that, their interests are not in satellite operations, but in playing with the next challenge...[Ref. 37:p. 1]

If Mr. Bruninga is correct, then a PANSAT designed to only interact with the amateur radio community would be vastly under utilized. A PANSAT designed to incorporate a primary and at least one secondary mission stands a far greater chance of providing tangible returns on the many thousands of man hours and dollars invested in PANSAT.

Because PANSAT is being built and funded by military organizations, the authorization to use military frequencies would allow the PANSAT design team the option of implementing various satellite modifications which could contribute to

military experiments pertaining to store-and-forward and/or SOTM communications.

B. BACKGROUND

The potential availability of UHF military frequencies for PANSAT is due in part to DARPA's success in obtaining frequencies for MACSAT and Microsat. Microsat shared some of the same frequencies with the U.S. Navy's FLTSATCOM satellites. Microsat's transponders had an uplink frequency 41 MHz *lower* than their downlink frequency. The U.S. Navy's FLTSATCOM transponders have an uplink frequency 41 MHz *higher* than their downlink frequency. [Ref. 38:p. 3] Both Microsat's and FLTSATCOM's diametrically opposed up and downlink frequencies made it possible for both systems to share the same frequencies at the same time with minimal interference.

As previously described in Chapter II, the Microsat constellation consisted of seven LEO satellites with each providing digital and analog regenerative transponder (sometimes referred to as "bent pipe") capabilities to system users. Due to various factors, an eighth Microsat was built, but never launched. When DARPA's MACSAT and Microsat contracts expired, the control and use of most remaining hardware was designated for transfer to Naval Space Command and Air Force Space Division. Naval Space Command received both ground control stations for MACSAT while the Air Force was designated to receive most other items (including the eighth Microsat).

C. MILITARY FREQUENCY APPROVAL

Gaining approval for using UHF frequencies in the Military band (225-400 MHz) for mobile users of satellites is a function of many variables. Mobile military satellite frequency approval is more likely to be granted to satellites which are:

- Experimental
- Store-and-forward,
- Burst packetized,
- Spread spectrum

Satellites which exhibit these features cause the least interference to other users and therefore, have the highest probability of being granted use of frequencies in the mobile military satellite bands. "The bands 235-322 MHz and 335.4-399.9 MHz are... allocated on a primary basis to the mobile-satellite services, *limited to military operations*." (italicized emphasis provided by the author) [Ref. 39:p. 4-96] To obtain use of military frequencies, NPS must work through a fairly involved set of procedures. The process of obtaining military frequency approval is a two step process. The first step, *system allocation*, takes about six months to complete and the second step, *frequency assignment*, takes three to six months to complete.

1. System Allocation

The first step towards attaining Military frequency approval is accomplished through submission of DD Form 1494 for all associated satellite and ground station communications equipment. These forms are reviewed and approved by the United States Military Communications Electronics Board (MCEB) and the National Telecommunications Information Agency (NTIA). A subcommittee of NTIA is the Spectrum Planning Satellite subcommittee (SPS). The SPS includes representatives from about 20 government agencies including the Federal Communications Commission, the National Sciences Foundation, the Federal Aviation Administration and representatives from each branch of the Armed Forces.

Copies of the MACSAT and Microsat DD Form 1494 have been made available to NPS by Bob Steel of the Space Applications Corporation. Copies of the RADCAL DD Form 1494 have been made available by the RADCAL Program Manager. Having access to DD Form 1494 for MACSAT, Microsat and RADCAL should greatly simplify the process for completing these forms for PANSAT. Once approval for PANSAT's Military communications system has been granted, PANSAT will be assigned a four digit J12 number. This number is required to proceed the next step.

2. Frequency Assignment

The second step includes submission of a proposal for military operational frequencies using NTP-6(C) (Naval Telecommunications Publication) and the Standard Frequency Action Format (SFAF). This proposal must be sent to the Naval Frequency coordinator for the Western U.S. at Point Mugu, CA where proposal format verification and local coordination is performed. The proposal will then be sent to the National level to the Naval Electromagnetic Spectrum Center (NAVEMSCEN) for national level coordination. National level coordination will be accomplished and the proposal will be submitted for National Level Approval. This processes can take from 90 to 120 days before authority to transmit is received.

D. PRELIMINARY RESULTS

1. General

Preliminary research results indicate that PANSAT could potentially be modified to have the following capabilities:

- Provide proof of concept for a low cost, GPS, Emergency Rescue Location System (ERLS);
- Provide proof of concept for AX.25, spread and/or non-spread spectrum, military store-and-forward satellite communications; and
- Provide proof of concept for military SOTM through the integration of the eighth Microsat.

Given adequate time and resources, PANSAT could undergo a vast number of programmatic modifications to accomplish a wide variety of tasks. NPS is not likely to apply modifications to PANSAT which provide redundant functions readily available on other systems. Only by reviewing other existing and/or planned satellite systems, can the utility for a modified PANSAT be estimated.

2. Search and Rescue Systems

a. Existing System

As referenced previously, the only global search and rescue system is several LEO "bent pipe" Search and Rescue Satellite Aided Tracking (SARSAT) transceivers and many widely dispersed Local User (ground) Terminals (LUTs). This system monitors distressed stations (downed aircraft or ocean vessel) transmission beacons on 121.5, 243.0 or 406.1 MHz. SARSAT must receive this beacon and relay it to the nearest LUT a minimum of three times (once each orbit) before the LUT can determine the approximate location of the distressed station. Computational procedures are cited more fully in Appendix C. This process takes a minimum of several hours to complete and provides location accuracy from two to 12 nautical miles.

b. Future Systems[11]

The Air Force Space and Missile Systems Center is developing a Combat Survivor / Evader Locator (CSEL) system to enable downed pilots in combat to securely transmit their location to friendly forces. This system is being designed as a military/government system to aid in the location and recovery of downed pilots. As conceptualized, this program could provide a means to locate and

11. Telephone conversation and interview with Major Charles Banning, Air Force Space and Missile Systems Center, and the author, 19 August 1992.

rescue combat survivors that is far superior to the method of homing in on the ELT's signal. CSEL will use advanced methods for determining the downed aviator's location which may or may not include standard GPS position locating techniques. Bent pipe transponders may be located on Defense Satellite Communications System (DSCS) III satellites and/or GPS satellites. The earliest this system could begin fielding is 1996.

3. US Army LEO Satellite Systems

a. *Current Systems*

Today the Army has no SOTM, store-and-forward experimental or operational satellite communication systems.

b. *Future Systems*

The USAF's Radar Calibration satellite (RADCAL) is scheduled for launch in May of 1993 and uses similar packet radio protocols developed for MACSAT. This effort may provide the Army with "assured access" to store-and-forward communications capability. RADCAL may also provide experimental SOTM communications capability. Unlike PANSAT (which will operate full duplex with the AX.25 packet radio protocol and have virtually no scheduling requirements) RADCAL (like MACSAT) may operate half duplex, with no error checking, no user acknowledgment and require rigorous scheduling coordination.

E. RECOMMENDED MODIFICATIONS

These modification proposals are analyzed at the systems application level as opposed to the systems design technical level. An in-depth technical study is required to determine the feasibility of each proposal. Figure 10 graphically represents modification proposals 1 through 4.

1. PANSAT System With No Modifications

Many complex factors beyond the scope of this thesis must be evaluated before any PANSAT design modifications are implemented. The shaded area marked #1 located in the upper right hand portion of Figure 10 represents the current PANSAT system design.

2. Create an Emergency Location Rescue System (ELRS)

PANSAT could be used as an integral part in developing and testing an experimental ELRS. The triangular box marked #2 located in the upper right hand portion of Figure 10 represents PANSAT's ELRS receiver. Working with the National Aviation Safety Office, a GPS module manufacturer (such as Rockwell International or Magellan), and the PacComm Corporation, NPS would initiate an experiment which could revolutionize the way distressed pilots, seaman and those lost on land are found and rescued. This experimental system would use a new GPS "Black Box" (GPSBB - created from the integration of a tiny GPS module, a tiny PacComm TNC and a PRC 90-2 or PRC 112 radio) and a 243.0 MHz satellite receiver located on PANSAT. The world-wide applicability of an operational system like this has the potential of saving thousands of lives over the next 10 to 20 years.

Conceivably, the GPS location of a distressed airman/seaman could be provided to rescue parties within minutes of transmitting a distress signal. The GPS module, PacComm TNC and PRC-90-2 each cost approximately $300-$400 (the PRC-112 cost is approximately $4,500-$5,500[12]). Using a PRC-90-2, total hardware cost for a prototype GPSBB could be as low as $1,000. Cost for constructing a 243.0 MHz satellite receiver is undetermined. NASA-Goddard has built SARSAT receivers in the past and may be able to provide some assistance.

12. Telephone conversation and interview with Major Charles Banning, Air Force Space and Missile Systems Center, and the author, 19 August, 1992.

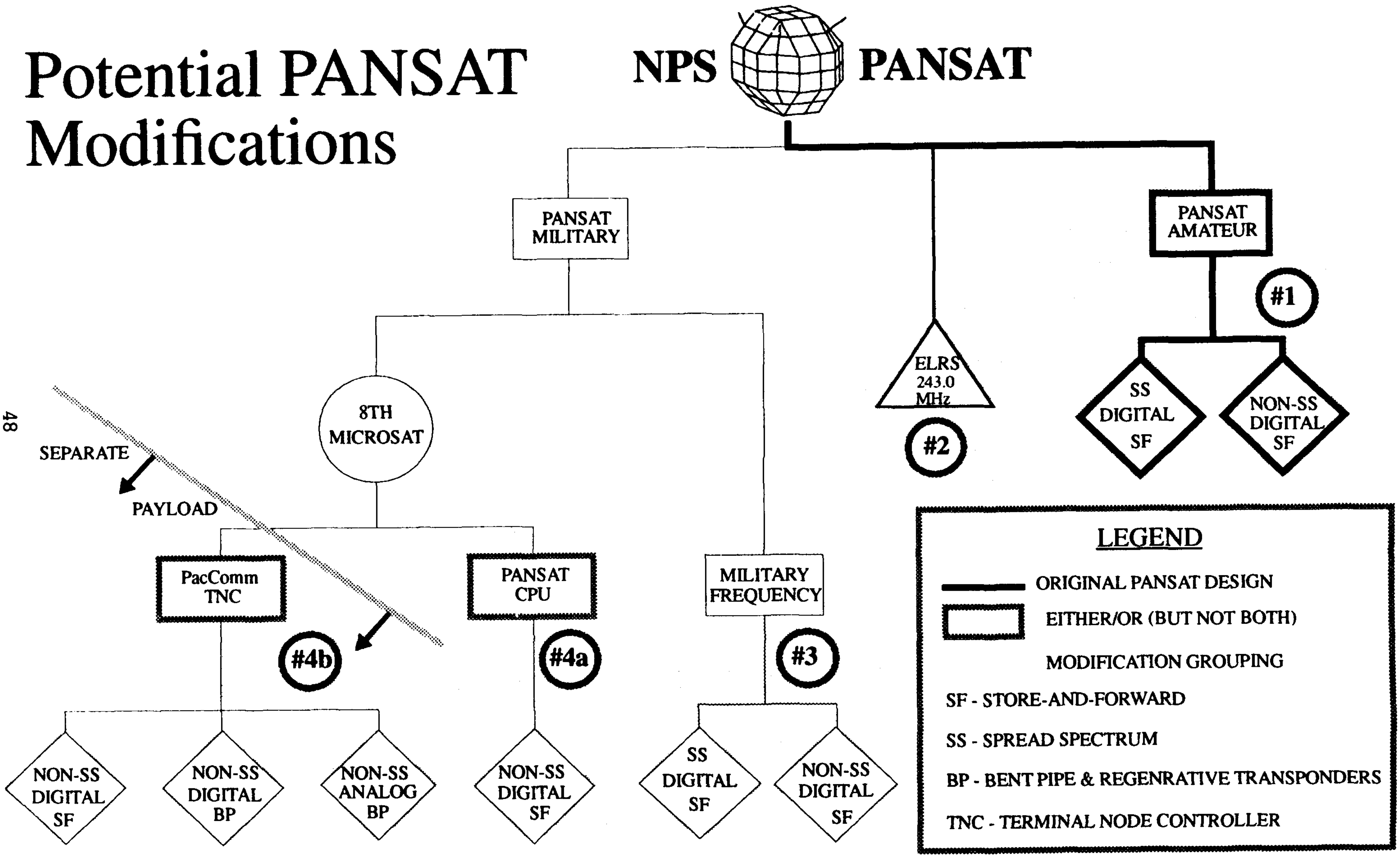

Figure 10: Potential PANSAT Modifications

3. Provide Experimental Store and Forward Capability

PANSAT is being designed to have a total of three megabytes of mail box RAM. The shaded area marked #3 located near the center portion of Figure 10 represents both PANSAT's store-and-forward, and spread and non-spread spectrum digital transceivers. With military frequency allocation/assignment, a pair of transceivers could potentially be built and installed on PANSAT to provide military spread and/or non-spread spectrum, store-and-forward capability.

4. Provide Experimental SOTM Capability

NPS could potentially integrate the eighth Microsat's receiver, transmitter, synthesizer and diplexer, controlling each subsystem either by PANSAT's CPU or by a PacComm TNC.

a. PANSAT's CPU as the Controller

The shaded area marked #4a located in the lower, center portion of Figure 10 represents the eighth Microsat's components controlled by PANSAT's CPU. Using PANSAT's CPU would save on power, volume and weight requirements, but may only provide store-and-forward capability and would also share PANSAT's 3 megabytes of RAM with the amateur communication sub-system.

b. PacComm's TNC as the Controller

The shaded area marked #4b located in the lower left portion of Figure 10 represents the eighth Microsat's components controlled by a PacComm TNC. Using the PacComm TNC could possibly allow the eighth Microsat's components to function as a separate payload on PANSAT (PacComm payload). Appendix B lists many of the features common to AX.25 TNCs. Using the PacComm TNC option, the PacComm payload would share power and serial command gateways

between itself and PANSAT's communications payload. In addition to serving as analog and digital, regenerative transponders, PacComm's payload provides limited amounts of store-and-forward capability in addition to PANSAT's three megabytes of mail box RAM.

F. DESIGN LIMITATIONS

Any modifications to PANSAT must be analyzed on a case by case bases from a power, volume and weight perspective. Each perspective is addressed briefly in the following paragraphs. Further research is required to determine how recommended modifications #2 through #4 would impact upon PANSAT's power, weight and volume design limitations.

1. PANSAT Power Constraints

A major concern of the PANSAT design team is power utilization. Due to PANSAT's limited surface area, a relatively small number of solar cells can be mounted to provide operational power.

> The PANSAT power subsystem will consist of a 12 volt unregulated bus supplied by solar cells and batteries. The planned solar cell set uses 17 exposed solar cell panels attached to the rectangular satellite surfaces (except the base). Each solar cell panel will use 256 cm^2 of solar cells for energy collection. The battery assembly will consist of a sealed container housing six battery packs of lead-acid batteries with six two-volt batteries per battery pack. The total energy storage capacity of the battery assembly will be 360 watt-hours. When the satellite is in the sunlight, the solar cells will provide power for operations and for recharging the batteries. When the satellite is in the dark, the batteries will provide all power requirements. [Ref. 40:p. 68]

The precise amount of power available to PANSAT subsystems as well as power required to run those subsystems has yet to be empirically determined. Actual power requirements will be determined once the designs for each of the various subsystems are completed.

Modifications to PANSAT would either have to fall within the current power budget or require switching the various subsystems on and off when appropriate. For example, implementing spread and/or non-spread spectrum store-and-forward capability on military frequencies (modification #3) could conceivably double PANSAT's modem and transceiver power requirements. If this implementation exceeded PANSAT's power budget, one alternative might be to operate only one set of subsystems at a time. Thus, while military store-and-forward operations were the priority, the PANSAT ground control station could turn the amateur subsystem #1 off (and turn the military subsystem #3 on). Ideally, the ELRS subsystem (modification #2) would be fully powered throughout PANSAT's operational life. However, once the ELRS experiment was performed, it too could be turned off. Implementation of modification 4a or 4b would also require additional power and might also have to be included in the power sharing on-off scenario previously described.

2. PANSAT Antenna Optimization

The completed PANSAT antenna design uses a tangential turnstile antenna to achieve a circularly polarized radiation pattern. This design consists of four identical antenna elements mounted as shown in Figure 11. Each element consists of 1/2 inch Stanley tape cut into 16.8 cm lengths. The operational bandwidth required for PANSAT's amateur configuration (modification#1) is 960 kHz at 437.25 MHz.The original PANSAT design study conducted by Daniel A. Ellrick tested the proposed antenna design from 370 MHz to 490 MHz and determined that with an appropriate impedance matching network, the tangential turnstile design could be used over a wide range of frequencies. [Ref. 40:pp. iii, 90] By broad banding PANSAT's turnstile antennas, adding the appropriate filters to each of PANSAT's receivers and transmitters and multiplexing communications payloads

together, it may be possible to support modifications #1-4 from an antenna design perspective. Further studies are required for conceptual and empirical verification.

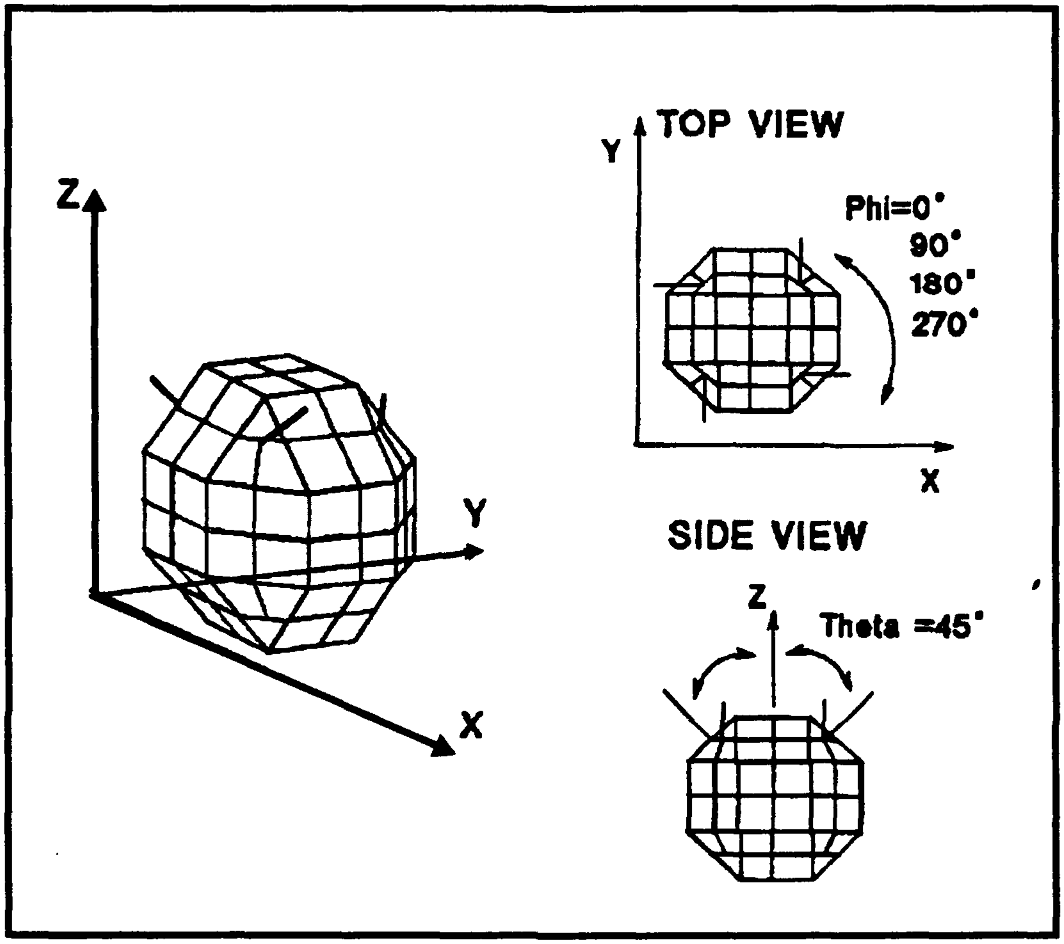

Figure 11: PANSAT's Tangential Turnstile Antenna design [Ref. 40:p. 40]

3. PANSAT Volume and Weight Restrictions

Figure 12 provides an approximation of PANSAT's internal structural layout. Although this is an approximate design, many members of the PANSAT design team indicate PANSAT has enough volume to accommodate other additional payloads. PANSAT's maximum allowable weight is 150 pounds. The total estimated weight of all planned subsystems for the original design is less than 100 pounds.

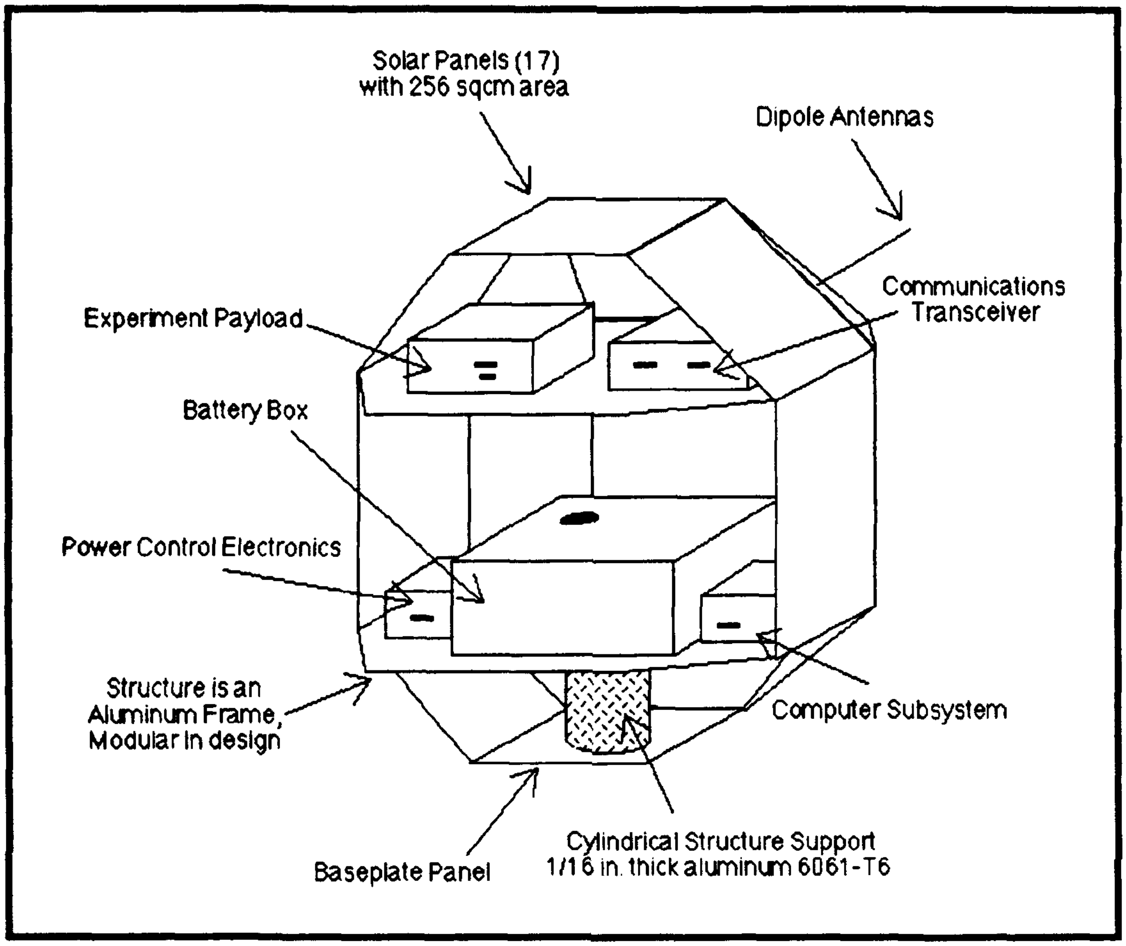

Figure 12: PANSAT's Internal Payload Configuration [Ref. 41]

G. FUTURE CONSIDERATIONS

1. PANSAT with Modifications

The exploration and/or implementation of the previously proposed modifications could provide a number additional of thesis opportunities to student-officers at NPS and could eventually result in extended communications service to a wide variety of users.

2. PANSAT Follow-on Satellites at NPS

Even if the modifications proposed in this chapter are not be implemented on PANSAT, opportunities exist to apply these modifications to the next NPS follow-on satellite. The Radiant Teak Experiment (RATE) is one potential, PANSAT follow-on satellite. The RATE satellite structure (see Figure 13) and various subsystems have been given to NPS for future satellite endeavors. If military frequency allocation/assignment is requested and approved for PANSAT and PANSAT is later determined unable to support military payloads suggested in modifications #3 or #4, those approved frequencies could become the baseline for the design of next NPS satellite system.

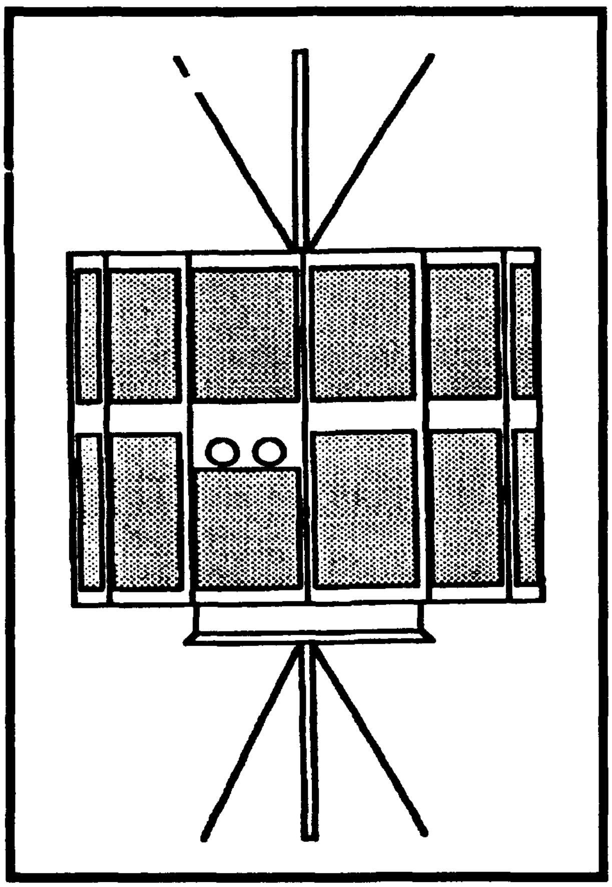

Figure 13: RATE [Ref. 42]

VI. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

The experimental use of PANSAT strictly on amateur frequencies should provide a tremendous service to the amateur radio community. However, a significant opportunity to exploit an even larger user base exists within the military's UHF frequency domain. Additional experiments with the Emergency Locator Rescue System (ELRS) on 243.0 MHz could improve the way distressed airman and sailors are located and rescued. Experimental Satellite Communications On The Move (SOTM) capability could be attained through the successful integration of the eighth Microsat's tunable receiver/transmitter group. Resources required to support these and other modifications could be provided by agencies interested in participating in unique experiments and/or obtaining assured access with PANSAT once it became operationally available.

A large proportion of potential PANSAT system users have either no secure transmission requirements and/or have no access to spread spectrum radio equipment. Most of these users are looking for the most reliable, simple to operate systems they can gain access to. With the availability of numerous, UHF, non spread spectrum military radios and keen interest in PANSAT's store-and-forward capability, designers should consider making PANSAT both spread and non-spread spectrum system capable.

The PANSAT design team has set February 1993 as the time when PANSAT designs will be finalized (no more modifications permitted). Design modifications cited in this thesis must be further developed from a technical perspective in the first quarter of Fiscal Year 1993 (if they are to be further considered for PANSAT).

There is moderate military interest in participating in PANSAT operational testing. There is definite military interest in PANSAT as a proven product. Systems

like PANSAT are drastically needed to provide services to ease strains placed on tactical, real time communications systems. Revised military doctrine calls for less logistical support to accompany initial and subsequent deployment of tactical forces. Tactical units will deploy forward, leaving the bulk of logistical units in the rear to deliver supplies forward when requested. Warehouses and administrative services are likely to remain in the U.S. The demand for "PANSAT type" systems will continue to grow.

In the future, an initial constellation of lightsats could inexpensively be placed in orbit as a secondary load on one of many possible launch vehicles. A constellation of three PANSATs could provide as much as 72 minutes per day of uplink / downlink transmission time [Ref. 43:p. 35]. Lightsats may provide surge type communications during the early mobilization phase of military operations as well as replace non-functional terrestrial systems in the aftermath of hurricanes and other natural disasters. Lightsat have the potential to provide a quick response, satellite communications system. To realize this potential, an appropriate number of preconfigured satellites and launch vehicles must be prepared and set aside for contingency purposes.

The addition of a military UHF capability and/or an ELRS experiment on PANSAT should improve PANSAT's Space Test Program (STP) ranking. Last year, PANSAT was ranked only 29 out of 35 military experiments scheduled for STP launch.

No matter how many communication assets are available, more will be desired. The ability to move non-critical traffic from command to alternate nets may provide as much operational utility as the command nets themselves since the operational value of a saturated command net is marginal at best. The basic rule of communications: you can never have enough. In times of crisis, every communication asset will be used.

B. RECOMMENDATIONS

The following recommendations are listed in priority order. In an austere resource environment, funding for future NPS satellites may be contingent upon providing tangible services to financial sponsors (which may in turn require military frequency band utilization). Thus, gaining approval for use of frequencies in the mobile satellite, military band is of paramount importance to current and future NPS satellites. Experience gained as a result of requesting military frequency access for PANSAT would simplify efforts required for future NPS, experimental satellite systems. Most of the PANSAT modifications addressed in this thesis require further technical study prior to implementation or rejection. The ELRS project requires continuous coordination between the PANSAT design team, the National Aviation Safety Office and PacComm Corporation. Continued coordination with other Department of Defense, space related agencies should provide NPS with access to the latest user requirements and technical information. For PANSAT to effectively support system users, these users must be identified early on and encouraged to work with the PANSAT design team to create a functional, user friendly operator interface. In all cases, steps taken towards future design changes must begin now.

1. Submit Request for Military Frequency Use

Desires to operate PANSAT within the military's UHF spectrum are considerable. Use MACSAT, Microsat and RADCAL DD Form 1494 as a baseline for PANSAT UHF, mobile, military satellite frequency requests. In particular, process all military frequency requests through the Naval Electromagnetic Spectrum Center. Provide copies of these request to the Army's Electromagnetic Spectrum Center to facilitate coordination of Army/Navy efforts for attaining PANSAT military frequency approval.

If the military frequency approval request is initiated by January 1993, system allocation could be granted as early as June 1993 and frequency assignment could be granted as early as October 1993 (two years prior to the late 1995 projected launch).

If military frequency requests are approved, integrate the operational military tests into the final phases of PANSAT system testing to generate military interest and support for follow-on systems.

2. Conduct Technical Investigations

Continue to exploit lessons learned from DARPA's MACSAT and Microsat programs. Consult with MACSAT and Microsat engineers and users to create the most effective, user friendly PANSAT interface possible.

Consult with DSI for requirements to integrate the eighth Microsat's basic communications components (receiver, transmitter, synthesizer and diplexer) with PANSAT. Determine microsat power, volume, and weight parameters.

Consider broad-banding PANSAT's tangential turnstile antenna design to encompass military UHF frequencies in addition to the amateur band already approved. Also consider making primary receivers and transmitters "tunable" to increase satellite utility.

Consider maximizing the system data rate and RAM to increase PANSAT user capabilities and future system utility.

Consider making PANSAT capable of switching between the spread and non- spread spectrum BPSK modems to potentially make PANSAT available to non spread spectrum users on both amateur and military frequencies.

Consider adding an additional receiver to increase satellite utility. PANSAT may be approved to transmit on 437.25 MHz, but it can passively receive on any frequency. Ideally, this additional receiver could be tunable to any frequency within

the 225 to 440 MHz range. This would allow PANSAT to exploit other missions yet to be defined.

Consider making PANSAT's non-spread spectrum modem compatible with existing military, UHF, satellite, communication radios. Current Army UHF radios are non spread spectrum systems which have narrow bandwidths of 5 and 25 kHz.

Consider using "off the shelf" lap tops and/or software for user terminal design to reduce cost and increase functionality. Consider using small hand held devices like Atari's palm top computer. This computer could be used in conjunction with a TNC and a small hand held UHF radio to send and receive data from PANSAT.

3. Coordinate ELRS Project

Work with the National Aviation Safety Office and PacComm to outline technical requirements and outline milestones for the ELRS Project.

Consider requesting NASA's Goddard Space Center assistance in developing an experimental, NPS, Emergency Locator Rescue System by providing the SARSAT 243.0 MHz receiver designs flown on several NOAA satellites.

Consult with Army Communication Electronic Command (CECOM) and possibly with Fort Ord Aviation Units with respect to attaining a PRC 90-2 or PRC 112 (with batteries) for use in the GPSBB unit addressed in Chapter III.

4. Increase Involvement with Military Space Agencies

Invite key lightsat advocates from ASTRO, A.S.I., ARSPACE and DARPA to future PANSAT design reviews.

Enroll PANSAT in the Annual Army Space Exploration Demonstration Program (AASEDP). This program is designed to show how new products make use of space to resolve tactical and non-tactical Army problems. This program also shows how new systems meet Army requirements.

Consult with DARPA, the Army's CECOM, Naval Space Command and amateur radio systems manufacturers to determine current and future UHF, spread spectrum modem and/or radio systems.

Consult with DARPA and SDIO for the latest, lightweight satellite components such as solar cells and computer processors. DARPA's Advanced Space Technology program is a potential source for new lightweight systems for spacecraft. SDIO has fostered miniaturized technologies as part of a drive to reduce cost of strategic defense employment.

APPENDIX A: PANSAT LAUNCH VEHICLES

A. GENERAL

There are numerous launch vehicles that could be used to launch all or part of a contingency PANSAT constellation. This appendix is taken from Chapter 3 "Operation PANSAT" [Ref. 43:pp. 16-31] by LT Theodore Vetter. The following six launch vehicles (LVs) are discussed individually, then compared at the end of this appendix:

- Pegasus
- Space Shuttle
- Titan II
- Scout
- Delta II
- Taurus

B. PEGASUS

Pegasus air launch vehicle is the latest method of launching small satellites. Figure A-1 shows Pegasus 1-3 stages. It utilizes a specially configured B-52 aircraft to carry it to a launch altitude of 40,000 feet. Fully loaded, Pegasus weighs 40,000 lbs. Since the B-52 maximum payload weight is 5,2000 lbs., it can carry a single Pegasus to the desired launch attitude.

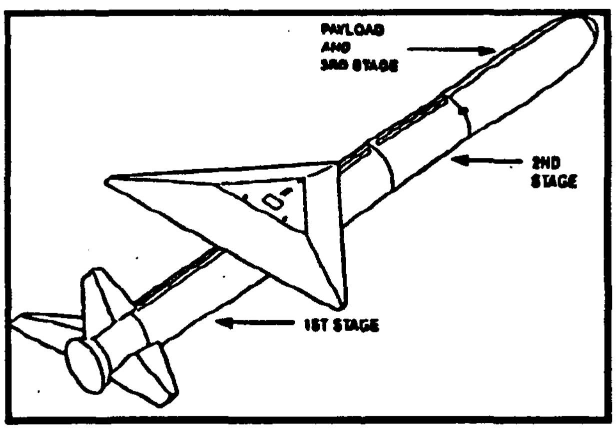

Figure A-1: Pegasus Air Launch Vehicle
[Ref. 44:p. 29]

Size and weight calculations indicate that Pegasus should be able to launch two PANSATs. The payload bay is depicted in Figure A-2 below. A possible launch configuration of three PANSATs is shown in Figure A-3.

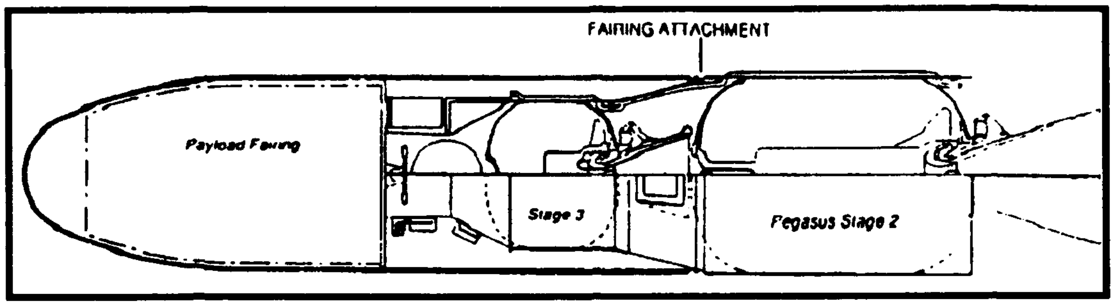

Figure A-2: Pegasus Payload Bay [Ref. 44:p. 38]

Pegasus as a launch vehicle for PANSAT has the advantage of being able to be launched at any desired inclination (because the B-52 can be positioned at any latitude). Pegasus can be precisely placed in proper orbit for any given situation. The only apparent disadvantage of the Pegasus launch vehicle is that there is one launch capable B-52 as of June 1992.

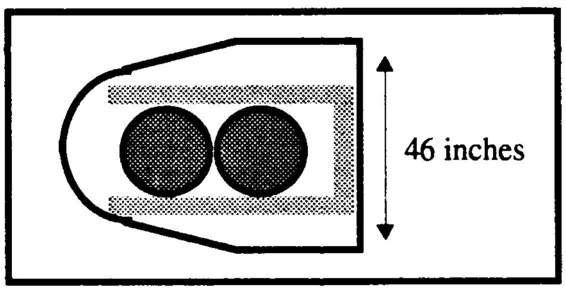

Figure A-3: Possible PANSAT Launch Configuration in Pegasus

The Pegasus payload and orbit capabilities are as follows [Ref. 44:p. 38]

- maximum payload weight:
    - 600 lbs (250 nm polar orbit)
    - 900 lbs (250 nm equatorial orbit
    - 510 lbs (300 nm 40° inclination)
- payload bay dimensions:
    - diameter 46"(tapered nose)
    - length 72"

- Launch Cost (1988 dollars):
    - per Pegasus $6 million
    - per PANSAT $3 million (2 PANSATs per Pegasus.)
    - per constellation: $6 million (2 satellite constellation.)

C. SPACE SHUTTLE

The shuttle's payload capacity is impressive. It is the most versatile platform currently available and would be able to launch and deploy an entire PANSAT constellation on a single mission. Figure A-4 shows the shuttle's open payload bay.

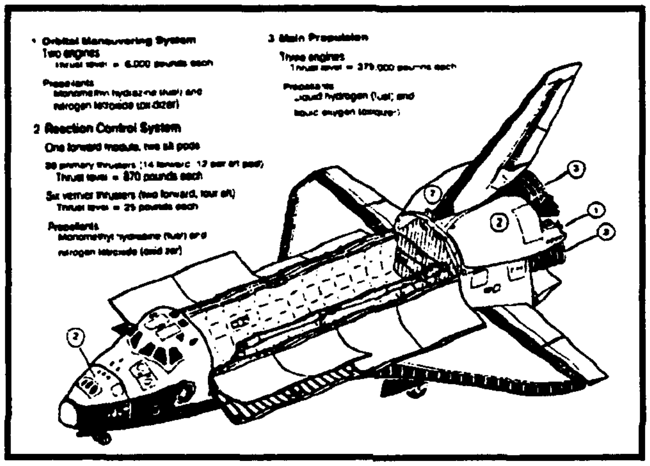

Figure A-4: Space Shuttle Cargo Configuration [Ref. 45:p. 108]

The shuttle has an existing method of launching small satellites called a Get-Away Special (GAS) canister. A GAS can is depicted in Figure A-5. There are two sizes of GAS container cans: standard and large. The standard GAS can measures 19" in diameter by 18.5" high. PANSAT was designed to be launched by the standard GAS can. If the shuttle was configured to fly a dedicated PANSAT deployment mission with no other payloads, The payload bay could be configured with a 'GAS bridge' consisting of 12 canisters. Another option to launch PANSAT from the shuttle would be to deploy a PANSAT sled containing multiple units from the shuttle cargo bay. The sled could then be manœuvered from a ground site to the proper orbital positions and PANSATs deployed individually.

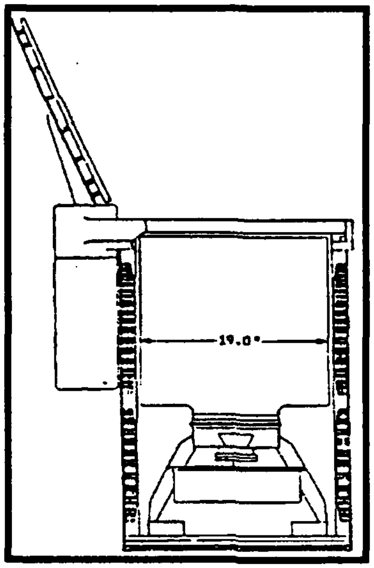

Figure A-5: Shuttle Get Away Special (GAS) canister [Ref. 45:p. 127]

Figure A-6 depicts a PANSAT deployment sequence from a GAS canister:

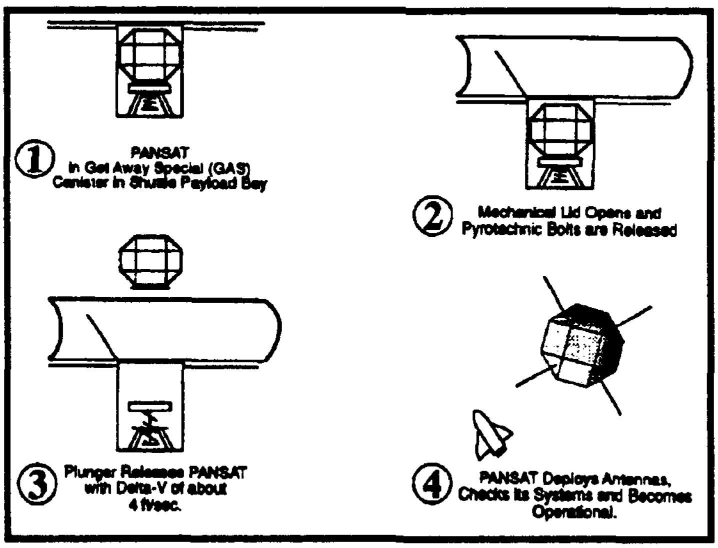

Figure A-6: Shuttle GAS payload deployment sequence

Space Shuttle payload statistics:

- Maximum payload weight:
    - 30000 lbs (300 nm / 28.1° inclination)
    - 18000 lbs (300 nm / 57° inclination)
    - 3000 lbs (260 nm / 98° inclination)
- payload bay dimensions:
    - diameter: 15 feet.
    - length: 60 feet.
- Launch Cost ($1988):
    - dedicated: $3000 per lb.
    - secondary: $65 per lb
    - Endeavor's maiden flight for Intelsat 6 recovery cost >$3.5x10⁶

D. Titan II

The Titan series of launch vehicles was first designed to launch ICBMs. NASA used Titan II for the Gemini manned space program. In 1987 the Titan II ICBMs were deactivated. In 1988 there were 55 Titan IIs remaining [Ref. 45:p. 137]. When converted for non-ICBM use, they are designated as Titan II SLV (Space Launch Vehicle). Figure A-7 shows a schematic of the Titan II launch vehicle.

Titan II SLV /payload statistics are shown below and in Figure A-8:

- maximum payload weight:
    - 3200 lbs (450 nm / 99° inclination / direct insertion)
    - 4500 lbs (450 nm / 99° inclination / split insertion)
- maximum payload dimensions:
    - 20' faring
        diameter: 111"
        length: 240"
    - 25' faring
        diameter: 111"
        length: 300"
    - 30' faring
        diameter: 111"
        length: 360"
- Launch Cost (1988 Dollars):
    - per Titan II: $43 million
    - per PANSAT: $4.3 million (10 PANSATs per Titan II)
    - per constellation: $43 million (10 satellite constellation)

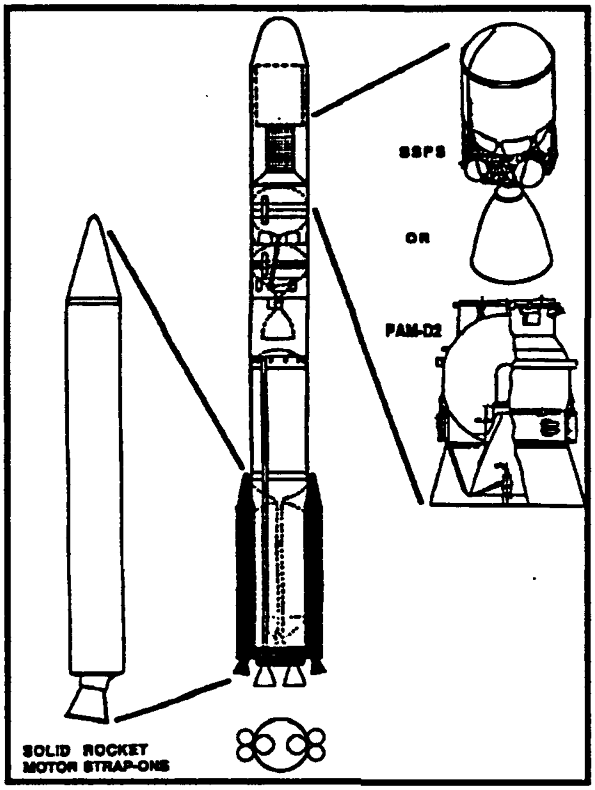

Figure A-7: Titan II launch vehicle [Ref. 46:p. 4-4]

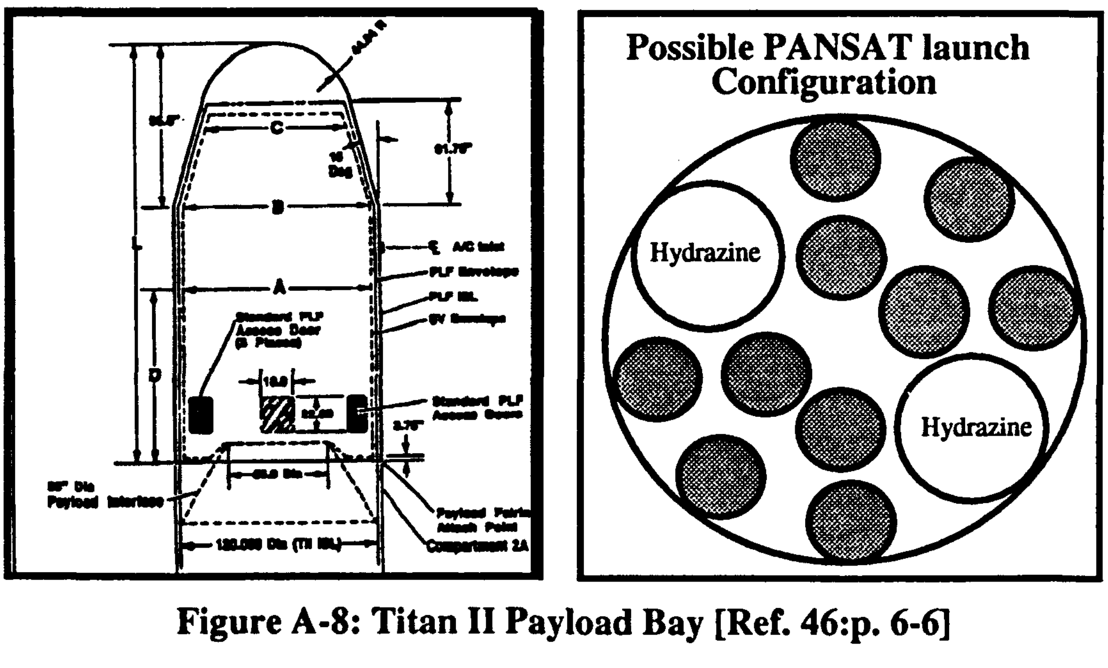

Figure A-8: Titan II Payload Bay [Ref. 46:p. 6-6]

E. Scout

The Scout was designed for orbital, probe and reentry experimental missions. It became operational in 1963. The improved Scout was introduced in 1986. It is a four staged, solid propellant system. Scout was designed for the smaller payloads and fits PANSAT launch requirements well. According to Lyons, in 1988 there were only 10 scout launchers remaining and each of them were committed to specific tasks. Figure A-9 shows a Scout launch vehicle on its tilted launcher. Figure A-10 shows a cut-a-way of both the original and improve Scout payload bays.

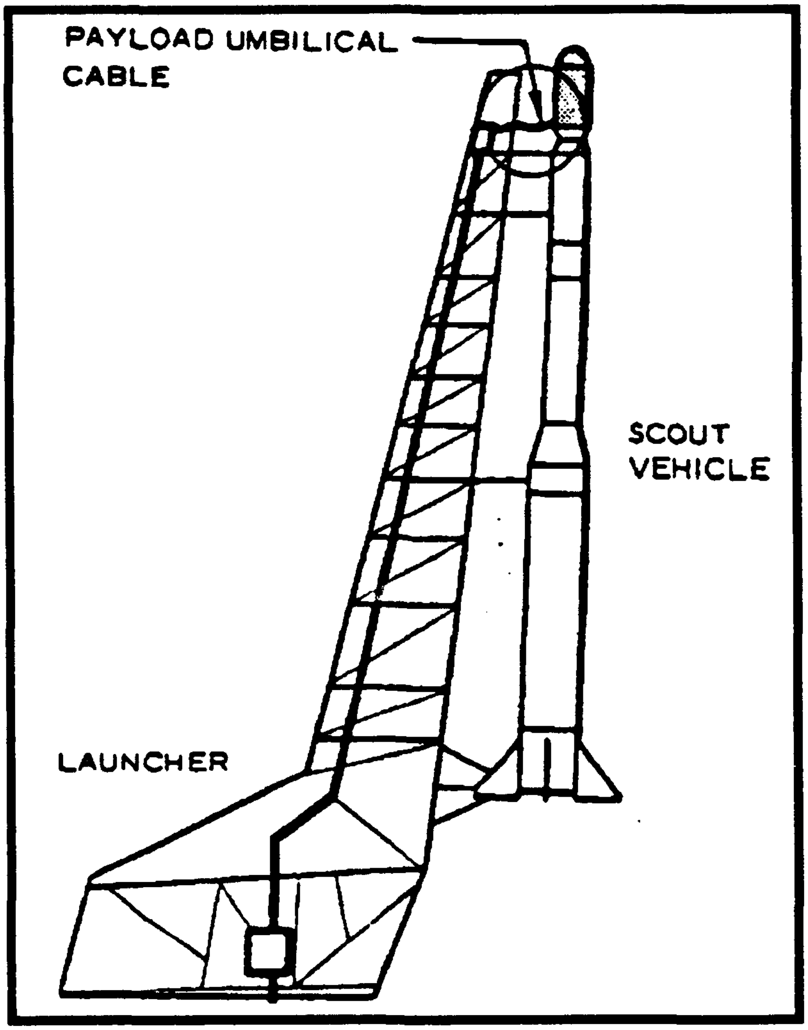

Figure A-9: Scout launch vehicle on tilted launcher [Ref. 45:p. 221]

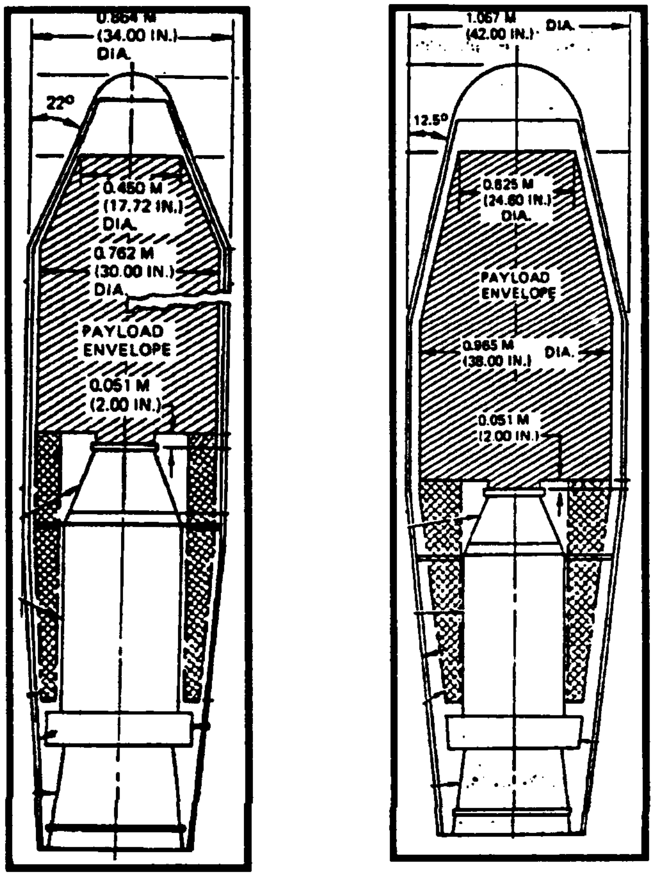

Figure A-10: Original (left) and Improved Scout (right) Payload Bay [Ref. 45:pp. 229, 230]

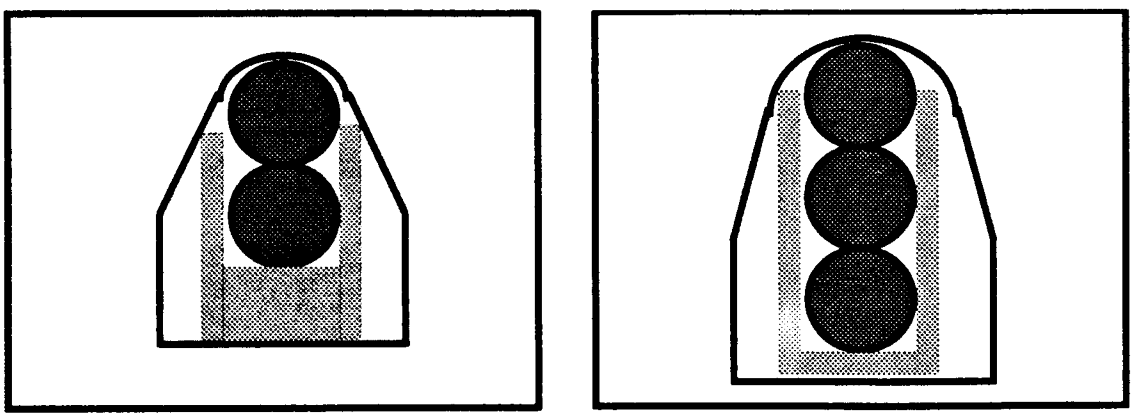

Figure A-11: Possible PANSAT configuration for the original (left) and the improved (right) Scout [Ref. 43:p. 25]

Scout Payload statistics:

Original Scout:

- maximum payload weight: 480 lbs
- payload bay dimensions:
  - diameter: 30"
  - length: 59"
- Launch Cost ($1988 millions):
  - per Scout: $9 million
  - per PANSAT: $4.5 million (2 PANSATs per scout)
  - per constellation: $9 million (2 satellites per constellation)

Improved Scout (change only)

- payload bay dimensions:
  - diameter: 38"
  - length: 61"

F. Delta II

General: The Delta are three stage rockets. The first stage is solid and the last two stages are liquid propellant. There are currently three delta vehicles available. From smallest to largest they are: 3920 / PAM, 6925 (two and three stage) and 7925 (two and three stage). The Delta vehicles were designed to put very heavy loads into very high orbits. (Examples: 5660 lbs to 450 nm 98.7 degree inclination sun synchronous orbit or 2120 lbs to 63.4 degree Molniya orbit.)

Delta II Payload Capabilities:

3920 / PAM (8' fairing)

- maximum payload weight:
  - 7610 lbs
- payload bay dimensions:
  - diameter: 86"
  - length: 184"

6925 (9.5' fairing)

- maximum payload weight:
  - 8780 lbs
- payload bay dimensions:
  - diameter: 100"

7925 (10' fairing)

- maximum payload weight: 11,110 lbs
- payload bay dimensions:
    - diameter: 110"
    - length: ~ 275"
- Launch Cost ($1988):
    - per Delta II: $37 million
    - per PANSAT: $3.7 million (10 PANSATs per Delta II)
    - per constellation: $37 million (10 satellites per constellation)

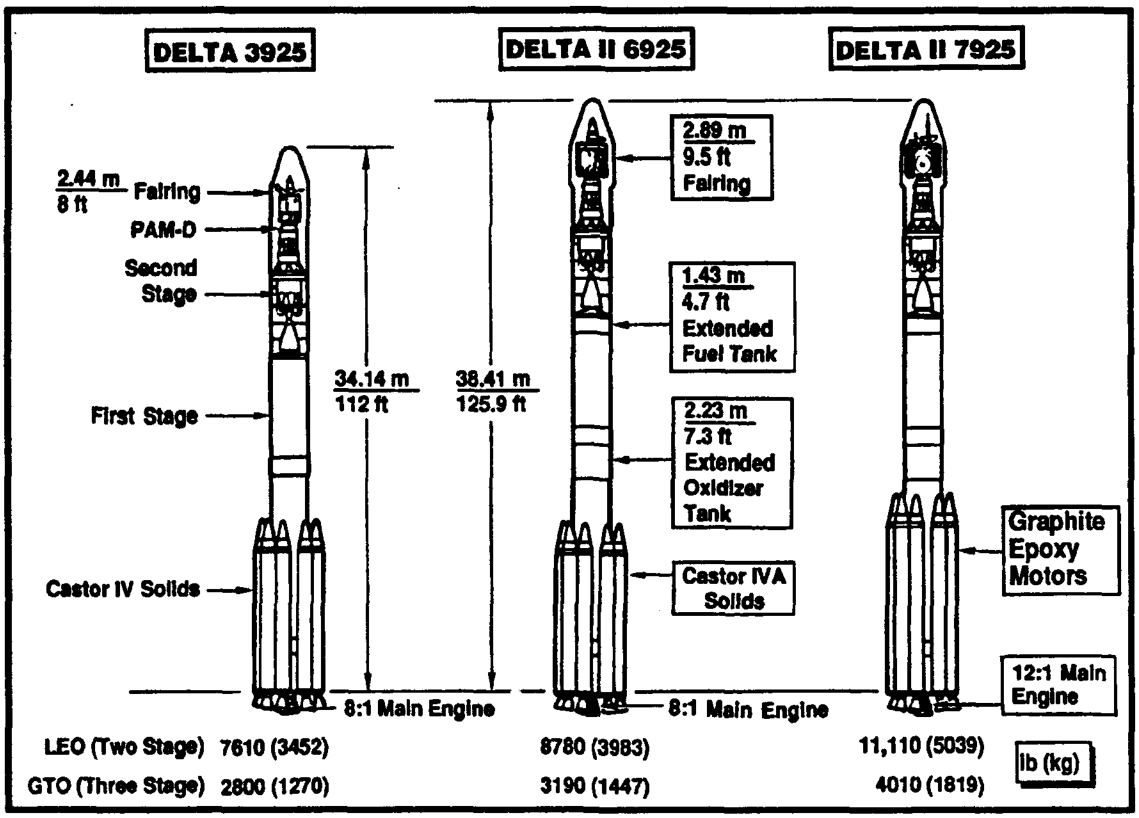

Figure A-12: Delta II Rockets currently available [Ref. 47:p. 7]

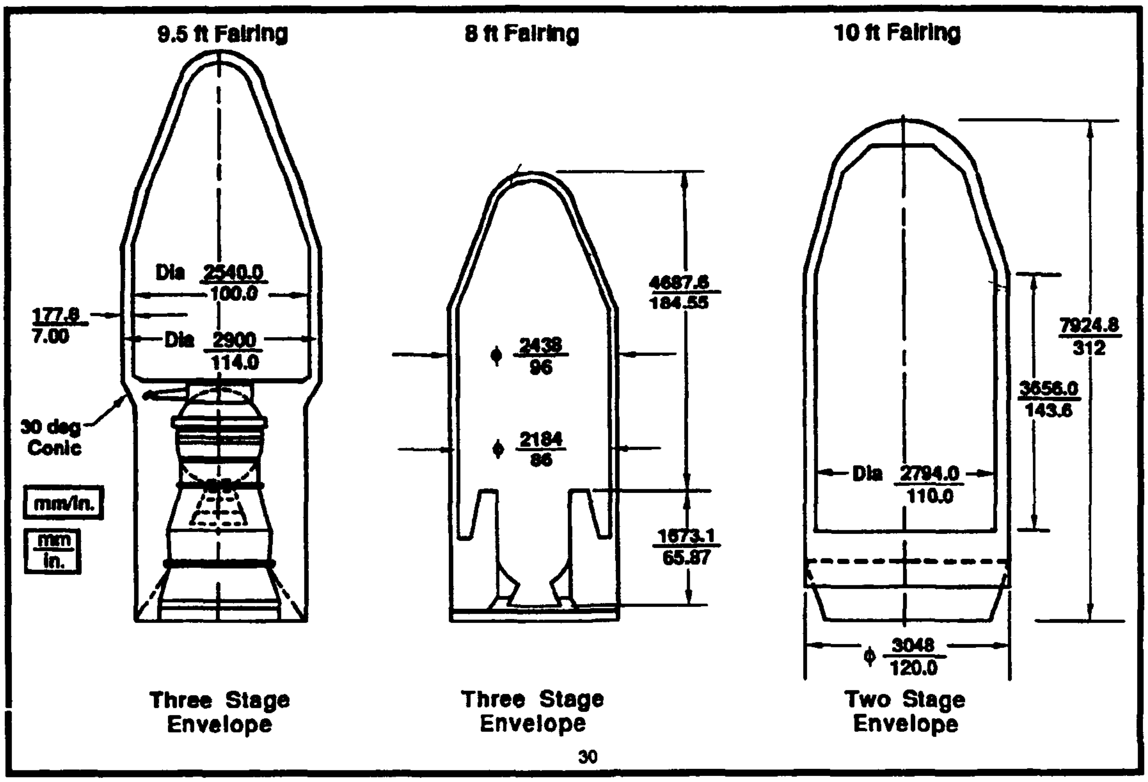

Figure A-13: Delta II Payload Bay Configurations [Ref. 47:p. 30]

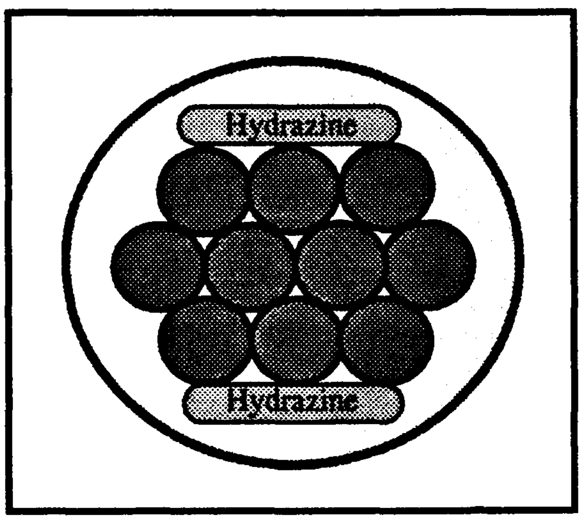

Figure A-14: Possible PANSAT configuration in Delta II 9.5 ft. faring [Ref. 43:p. 27]

G. Taurus

Taurus is a newly developed expendable launch vehicle. It is a combination of a Peacekeeper missile and Pegasus air launch vehicle.Taurrus will have a flexible launch siting because it will have a transportable launch assembly and launch stand that will not require permanent launch pads. DARPA is the main backer and controller of this launch vehicle. [Ref. 48:p. 66]

Taurus payload statistics:

- maximum payload weight:
  - 3200 lbs (100nm/28° inclination)
  - 2600 lbs (100 nm / 90° inclination)
  - 830 lbs (GEO)
- payload bay dimensions:
  - diameter:4.8 ft.
  - length: 21.7 ft.
- Launch cost: (1988 dollars)
  - per Taurus: $10.9 million
  - per PANSAT: $1.9 million (10 PANSATs per Taurus)
  - per constellation: $10.9 million (10 satellites per constellation)

H. LAUNCH VEHICAL COMPARISONS

PANSAT is currently planned to be completed and launched in late 1995. Assuming that PANSAT, as an experimental satellite, proves to be a reliable and useful communication asset, it is conceivable that a constellation of PANSAT follow-on satellites could be built and held in reserve for contingency purposes. Table A-1 compares some of the more common elements of the launch vehicles previously addressed.

The size of the contingency constellation need would determine the launch vehicle, deployment system, method of storage and time required to launch. For example, if a two satellite constellation was required, then a two satellite Pegasus launch vehicle configuration could be prepared and assembled complete with two PANSATs mounted in the payload area and stored until needed. Prior to launch, the

PANSATs could be computer tested, the launch vehicle fueled and farings attached. The Pegasus would then be moved to the waiting B-52 and subsequently deployed.

If a 10 PANSAT constellation was required, either 10 PANSAT GAS cans could be removed from storage and launched on a shuttle mission, or a previously manufactured deployment sled with 10 PANSATs could be loaded into the Shuttle bay. Given the Shuttle's protracted payload schedule and time between launches, this scenario does not lend itself to a short notice missions.

TABLE A-1: LAUNCH VEHICLE COMPARISONS

	Pegasus	Shuttle	Titan II	Scout	Delta II	Taurus
Proposed Weight	510 lbs	450-900 lbs	2500 lbs	480 lbs	2500 lbs	3200 lbs
altitude	300 nmi	300nmi	300nmi	300 nmi	300 nmi	100nmi
inclination	40 deg	57 deg	99 deg	------	------	28 deg
Max Inclination	90 deg	98 deg	99 deg	------	------	90 deg
weight	600 lbs	3000 lbs	4500 lbs	------	------	2600 lbs
altitude	250 nmi	260 nmi	450 nmi	------	------	100 nmi
Cost/PAN-SAT	~$3 million	variable*	4.3 million	~$4.5 million	$3.7 million	$1.8 million
Availability	indefinite	indefinite	indefinite	??????	??????	1993?
Other	-------	------	secondary payload available	------	secondary payload available	830 lbs to GSO

* Shuttle mission cost depends upon a number of factors. Purchasing an entire Space Shuttle mission for launching a PANSAT constellation would cost DoD $115 million. [Ref. 48:p. 44] A single GAS launch could cost between $10,000 and $30,000.

APPENDIX B: AMATEUR RADIO LINK LAYER PROTOCOL

A. GENERAL

AX.25 specifies the content and format of an amateur packet radio frame and how that frame is handled by packet radio stations. AX.25 works equally well in either half-duplex or full-duplex radio environments. The intent in this appendix is to provide an overview of basic AX.25 link-layer protocol features of critical importance to PANSAT and PANSAT system users. This appendix is predominantly a summary from Chapter 3 of Stan Horzepa's book entitled *Your Gateway to Packet Radio*, (American Radio Relay League, 1989).

1. AX.25 Frames and Fields

An AX.25 transmission consist of three types of information blocks called frames: Information (I-frame), Supervisory (S-frame) and Unnumbered frame (U-frame), s. Tables B-1 and B-2 each depict various AX.25 frame and field formats. An *I-frame* contains the user data while an *S-frame* acknowledges receipt of *I-frames* and/or request retransmission of *I-frames*. *U-frames* provide additional control not relevant to a general overview and will not be further defined.

Each frame is subdivided into smaller blocks called fields. Field lengths are measured in octets (an octet is equivalent to a byte or eight bits). Each frame contains a start and stop flag field, an address field and a frame check sequence (FCS) field. The flag field marks the beginning and ending frame. The address field contains the call sign of the source and destination of the frame. AX.25 protocol permits the use of up to eight relay stations (these stations are referred to as digipeaters). The control field indicates the frame type (I, S or U frame). The FCS field is used for fame error checking. The FCS field is recalculated by the receiving station. If the recalculated FCS number (a 16 bit number) does not match the

received FCS number, the frame is rejected and the frame must be retransmitted. Information frames contain two additional fields: protocol identifier (PID) fields and information fields (I-fields). The PID indicates the type of network layer protocol in use. An *I-field* contains the actual data the user is sending. The maximum length of an *I-field* is 256 octets.

TABLE B-1: UNNUMBERED AND SUPERVISORY FRAMES [Ref. 25:p. 3-6]

Field	Flag	Address	Control	FCS	Flag
Length	8 bits	112-569 bits	8 bits	16 bits	8 bits
Contents	01111110	call signs of destination, source and digipeaters	Frame type	Calculated Value	01111110

TABLE B-2: INFORMATION FRAME [Ref. 25:p. 3-6]

Field	Flag	Address	Control	PID	Information	FCS	Flag
Length	8 bits	112-569 bits	8 bits	8 bits	N x 8 bits	16 bits	8 bits
Contents	01111 110	call signs	Frame type	Layer 3 type	User data	Calculated Value	01111 110

2. User Stations

Users should be able to access the satellite from any position on Earth with a personal computer, Terminal Node Controller (TNC), appropriate software and a satellite antenna. Figure B-1 depicts a typical Amateur packet-radio installation. PANSAT spread spectrum capability will require users to attain spread spectrum compatibility with PANSAT via additional hardware and/or software. Since PANSAT will be the one of the first LEO satellites (if not the first) to operate using

spread spectrum, new software and/or hardware will have to be developed to permit spread spectrum operations.

Originally, the Terminal Node Controller (TNC) was strictly a packet assembler-dissassembler (PAD). A PAD accepts data from the computer and formats it into AX.25 frames for transmission. It also accepts packet frames via the radio's receiver and modem. A modern TNC includes both PAD and modem functions. Figures B-2 and B-3 each respectively depict a block diagram for a typical Amateur radio TNC and modem.

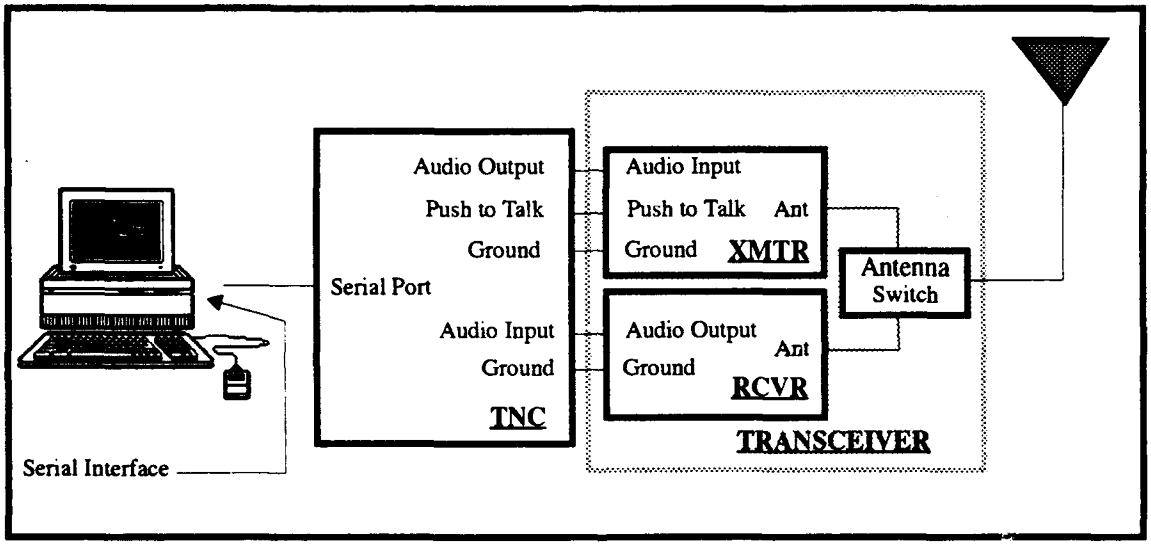

Figure B-1: Wiring diagram for a packet-radio system [Ref. 25:p. 5-9]

> Primary components in a typical Amateur TNC are the microprocessor and the HDLC (High Level Data Link Control procedure). The HDLC controller formats data from the microprocessor into frames that are transmitted over the air and it extracts data from each received frame for transfer to the microprocessor... The HDLC also calculates the FCS when a frame is assembled in preparation for transmission and recalculates the FCS for each frame received over the air to check its integrity. [Ref. 25:pp. 3-9:3-12]

In most applications, the TNC connects to the computer via a serial interface that is compatible with RS-232-C specifications. Some TNCs provide a

parallel interface as well. A serial interface transfers characters one bit at a time, while a parallel interface transfers characters one character after another by simultaneously transferring all the bits that make up each character. TNCs have erasable programmable read only memory (EPROM) and random access memory (RAM). RAM is used to temporarily store information (frames in queue for transmission, received frame and system variable). Non-volatile RAM is used to store TNC parameters that may be user defined. This data will remain stored in the TNC even after the TNC is turned off. [Ref. 25:pp. 3-10:3-12]

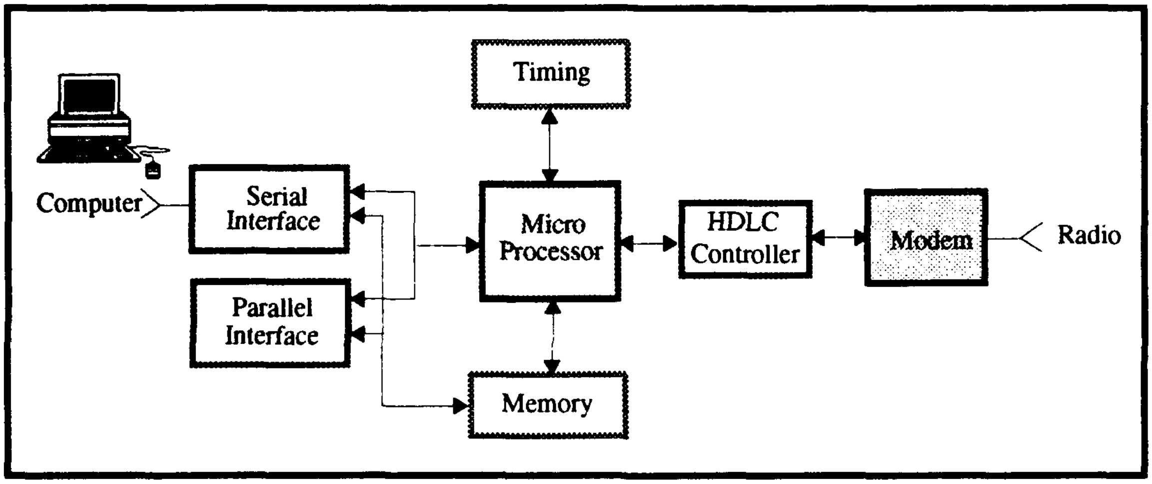

Figure B-2: Functional Block Diagram of a TNC [Ref. 25:p. 3-6]

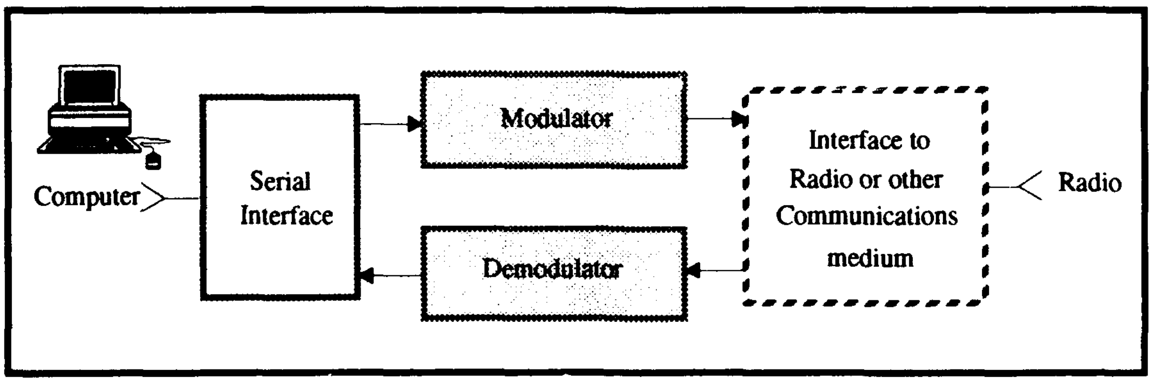

Figure B-3: Functional block diagram of a modem [Ref. 25:p. 3-6]

APPENDIX C: SEARCH AND RESCUE SATELLITE (SARSAT)

A. GENERAL

Today, the world depends exclusively upon Search and Rescue Satellite Aided Tracking (SARSAT) receivers in Russian *Cosmos* and U.S. *NOAA* satellites to locate downed aircraft that can not readily be found via terrestrial means. The purpose of this appendix is to describe the current search and rescue system's functions and shortfalls so a better appreciation of the potential contribution of the Emergency Locator Rescue System(ELRS) proposed in Chapters III and V can be more fully appreciated.

B. THE SARSAT SYSTEM

Downed aircraft distress signals originate from the aircraft's "black box" and are transmitted over three frequencies (121.5, 243.0 for older transmitters and 406.1 MHz for newer transmitters).

> Many aircraft and ships carry small [Emergency Locator Transmitters (ELT)] transmitters that may be used to broadcast emergency signals. However, because of their limited power, they have a short range. Thus, in most cases, rescue organizations must be alerted to the emergency by other means and home in on the transmitted signal only after they reach the vicinity of the emergency. Since satellites see a large portion of the Earth, they have a much better chance of receiving these emergency signals. [Ref. 49:p. 295]

The U.S. SARSAT contribution was developed by NASA's Goddard Space Flight Center. These satellites are in a polar, low earth orbit between 400 and 550 nmi. The Russian SARSAT receiver is called COSPAS (from the Russian words for Space System for the Search of Distressed Vessels). These distress signals must be received a minimum of three times by a Local User Terminal (LUT) before an approximate location of the distress signal can be determined. The ELTs emit a non-directional beacon. Figure C-1 depicts the ELT signal's reception requirement for

line-of-sight between the sender and receiver.The motion of the satellite over the beacon generates the Doppler shift used for position estimation. Location accuracy is about 12 nautical miles with the older transmitters and better than 2 nautical miles with the newer, 406.1 MHz transmitters. LUT stations are located in the United States, Russia, France, Canada, United Kingdom, Norway, India, Brazil and Chile. Figure C-2 depicts the SARSAT Regional Coverage System. These centers communicate with each other and with rescue coordination agencies from each respective country. [Ref. 49:p. 296]

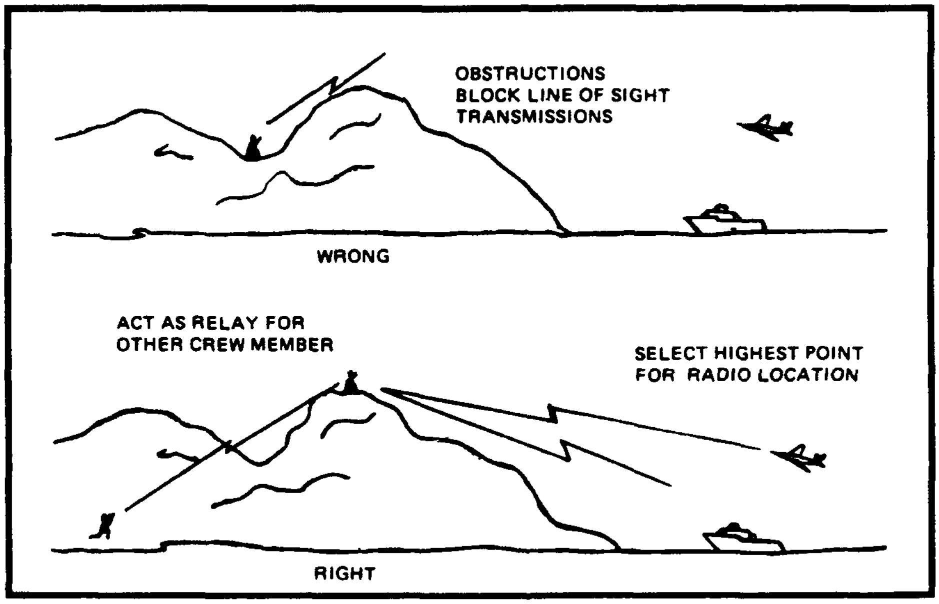

Figure C-1: Line of Sight Required for ELTs [Ref. 29:p. 3-11]

For this rescue system to work, the ELT distress signal must be strong enough to be received by the SARSAT receiver and it must continue to transmit over an extended period of time. Because each orbit takes 90 to 100 minutes, this triangulation process takes many hours to determine an approximate location.

Once the approximate location of the distress signal is determined, this location is transmitted to appropriate search and rescue authorities for investigation. Once an

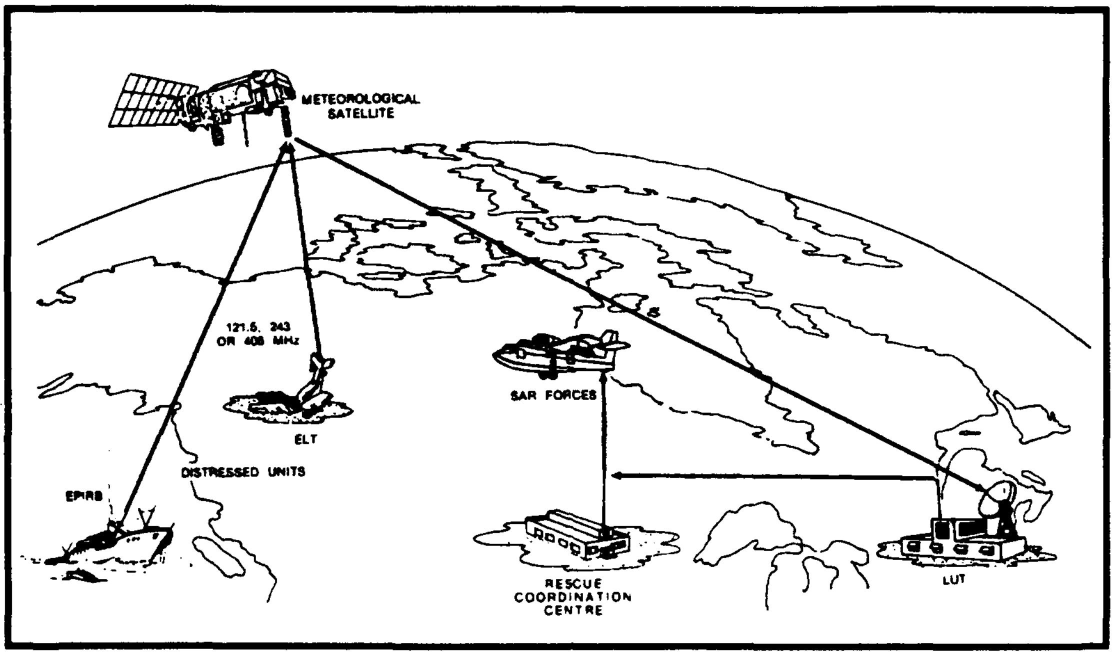

Figure C-2: SARSAT Regional Coverage System [Ref. 28:p. 21-10]

ELT beacon location has been estimated, the FAA notifies the Air Force Rescue Coordination Center (RCC) at Scott Air Force Base in Illinois. Normally the Air Force notifies the appropriate state agency and then the Civil Air Patrol.

LEO satellites carrying SARSAT receivers experience considerable Doppler shift (approximately 3kHZ) of the ELT signal. The technique of obtaining position information from a curve of Doppler frequency shift verse time for a satellite's pass involves several steps, as shown by the software flow chart in (Figure C-3). First corrections must be applied to the received signal to compensate for Doppler on the downlink and to average out noise effects. Then the zero Doppler, or point of closest approach of the satellite to ELT, must be determined with as much accuracy as possible. This is accomplished by the plotting (Doppler) frequency shift as the dependent variable (y-axis) as a function of the GMT the signal is received as the independent variable (x-axis). The slope of the Doppler curve at this point is used to calculate the range from satellite to ELT. The range is in turn used, along with satellite orbital data, to determine two initial estimates of possible positions on the earth's surface. These two positions are symmetrically located on each side of the

satellite orbital track. One position is the true ELT, while the other is a phantom location.

In an operational SARSAT system, the resolution of the ambiguity would occur by using data from a second satellite pass, by modelling the small differences in the two Doppler curves due to the rotation of the earth, or at worst, by a check of both indicated positions. The estimated ELT positions are used to compute predicted Doppler curves, and an interative procedure is used to solve for a final position which produces the best fit of computed Doppler data to the measured Doppler curve.[Ref. 28:p. 21-3]

C. SARSAT SHORTFALLS

Signals from ELT's using the older transmitters (121.5 or 243.0 MHz) are retransmitted in real time only. If no ground station is in view, the signal is lost [forever]. In contrast, the 406.1 MHz signals are processed on the satellite; the resultant data is retransmitted and stored for later transmission to other ground stations. The battery life of the nominal ELT ranges between 24 and 48 hours.

The latest FAA figures reported a 99% false ELT alarm rate. The ELTs are terribly unreliable. Some ELTs activate on hard (but safe landings). Other ELTs are inadvertently switched on by operators. Irrespective of this 99% false alarm rate, every distress signal must be fully investigated. As a result, an incredible amount of time and resources are expended by search and rescue teams to investigate each of these distress signals.[1]

The probability of saving an injured aircraft crash survivor's life falls off rapidly after the first hour. The FAA reports an airplane crash victim has less than a 50% chance of recovery before dying of injury or exposure.

The life expectancy of an injured survivor decreases as much as 80% during the first 24 hours, while the chances of survival of uninjured survivors rapidly diminishes after the first three days... Time works against people who... are not

1. Telephone Conversation and interview with Brian Dean, National Aviation Safety Office, and the author, 14 Sep. 1992.

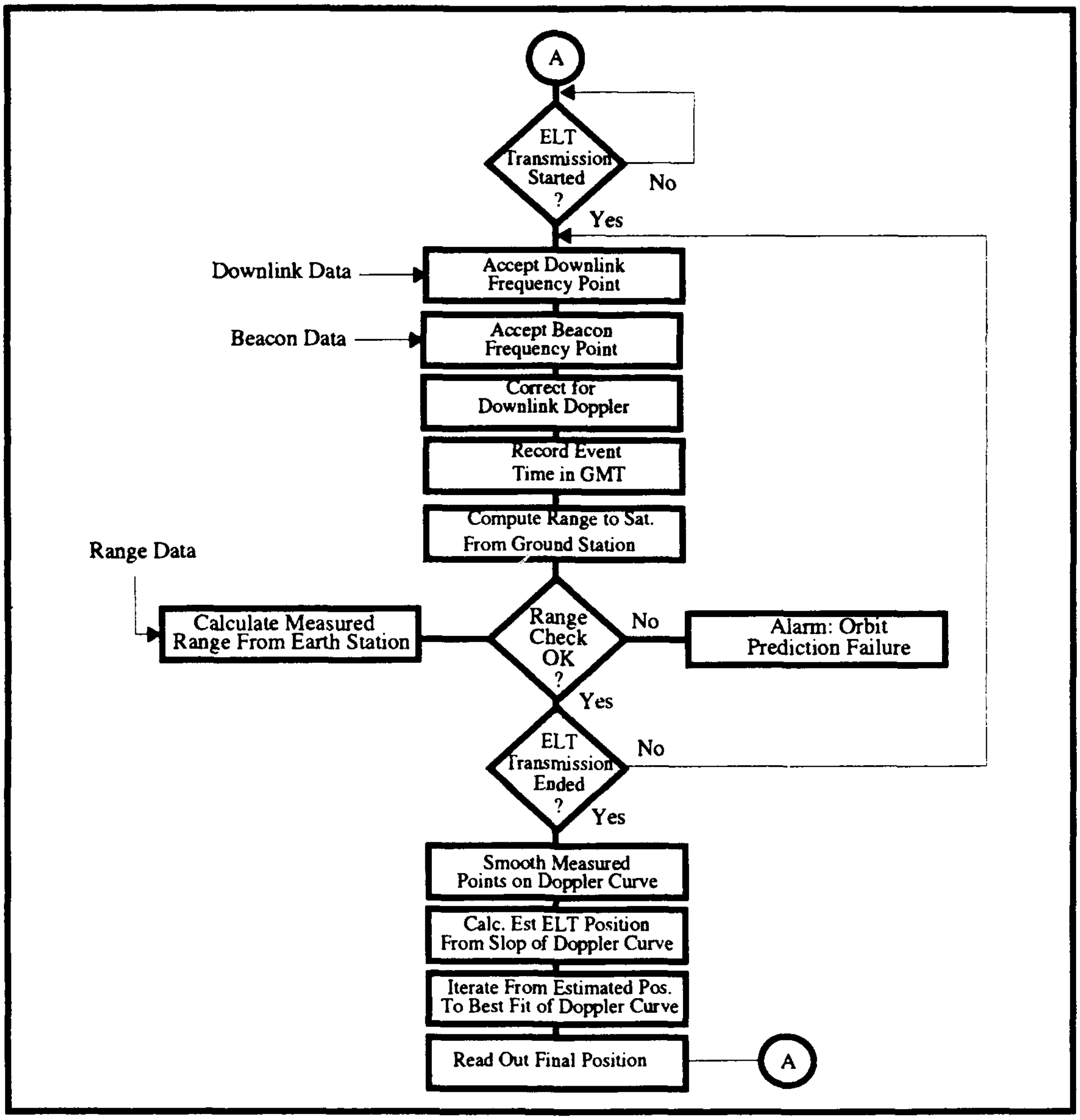

Figure C-3: SARSAT System Software Flowchart [Ref. 28:p. 21-8]

on a flight plan, since three days normally passes before family concern initiates a national search and rescue effort [Ref. 50:p. 1]

Less than two percent of aircraft crash victims are found via ELT beacons. Mr. Dean from the National Aviation Safety Office, stated that "we need to enhance the survivor's ability to send their location to someone who can help them. We do not want to do a *search* and *rescue*. We want to do a *rescue*!"

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Captain (P) Robert A. Payne Jr. was born on 27 January 1959 in Bryan, Texas. He graduated from high school in 1977 from Arlington High School in Arlington, Texas. He graduated from the United States Military Academy (West Point) in May of 1981 with a Bachelor of Science degree in Mechanical Engineering and a commission in the United States Army. Upon graduation, he attended the Field Artillery Officer Basic Course at Fort Sill, Oklahoma.

In December of 1981, he was assigned to the 1st Battalion, 21st Field Artillery, First Cavalry Division, Fort Hood, Texas where he served as a Fire Support Team Chief, Battery Fire Direction Officer, Battery Executive Officer and Battalion Fire Direction Officer. In June of 1985 he was reassigned to Headquarters Battery, Division Artillery, First Cavalry Division, as Division Artillery's Fire Direction Officer. From July 1986 until February 1987 he attended the Field Artillery Officer Advanced and Cannon Officers Course at Fort Sill, Oklahoma.

In March of 1987 he was assigned to the 7th Battalion, 8th Field Artillery, 25th Infantry Division (Light), Schofield Barracks, Hawaii where he served as the Battalion Targeting Officer, Battalion Plans and Operations Officer and Battery Commander of a 105mm (towed) firing battery. Upon successful completion of a 19 month command, he was reassigned to Headquarters Company, 25th Infantry Division (Light) as a Division Plans and Exercises Officer.

In July of 1990, he reported to the Space Sciences Curriculum at the Naval Postgraduate School in Monterey, California to pursue a Masters of Science degree in Systems Technology (Space Systems Operations).

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